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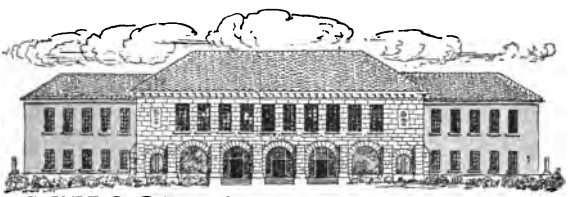

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NATURAL PHILOSOPHY

LESSONS IN PHYSICS

BY

C. L. HOTZE

Author of
"First Lessons in Physiology," "Questions and Problems in Physics,"
"First Lessons in Physics," etc.

REVISED AND ENLARGED
BY
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PREFACE.

This Treatise on Physics differs from the author's First Lessons in Physics in this, that, while the general plan and arrangement of the latter have been preserved, the present volume has been greatly enlarged and revised to meet the requirements of the present day. It must, therefore, be considered a new work. Much of the material of the previous work has been incorporated into this.

So far as practicable, experiments precede the statement of definitions and laws. The experiments can nearly all be made with very simple and inexpensive apparatus. For several years there has been a growing tendency in the schools to indulge in laboratory methods. An effort has been made to adapt this book to such needs, especially in those cases where the amount of time allotted to the study of Physics does not make it advisable to use both a text-book and a laboratory manual.

As Physics is usually the first branch of Natural Science studied in our schools, the simplest language has been employed and the use of technical terms, except where they seemed necessary to the better comprehension of the subject, has been avoided. The vast majority of students of Natural Philosophy have little use for technical terms.

Numerous diagrams and illustrations have been introduced wherever it was thought that they would assist the pupil in understanding the text.

The aim has been to make this work a short outline of a course in Physics, to occupy the student (taking five lessons a week) for one year and, at the same time, to give him the preparation in this study now required for entrance to most of our colleges. For this reason, many topics which usually encumber most of our text-books, have been eliminated.

It is intended, then, that this book should meet the following conditions prevailing in the vast majority of our schools: —

1st. A growing tendency toward experimental work.

2d. The inadequate equipment of school laboratories.

3d. The short time allotted for this study.

4th. To give sufficient preparation for entrance to college.

The author would be glad to receive suggestions from any who may use this book.

PUBLISHERS' NOTICE.

In order to distinguish this revision from the older editions, the name is changed to "Lessons in Physics."

CONTENTS.

PART I.— MATTER AND MOTION.

LESSON.		PAGE.
I.	Properties of Matter	1
II.	Properties of Matter (continued)	6
III.	Properties of Matter (continued)	11
IV.	Properties of Matter (continued)	14
V.	Properties of Matter (continued)	17
VI.	Properties of Matter (continued)	22
VII.	Motion	25
VIII.	Laws of Motion	30
IX.	Third Law of Motion	35
X.	Review of Matter and Motion	41

PART II.— FORCE AND ENERGY.

XI.	Forces	46
XII.	Falling Bodies	51
XIII.	Center of Mass	58
XIV.	The Pendulum	66
XV.	Measurement of Forces	70
XVI.	Energy	77
XVII.	Review of Force and Energy	83

PART III.— MACHINES.

XVIII.	The Pulley — Weight — Power	88
XIX.	The Lever	93
XX.	Wheel and Axle	95
XXI.	Clocks	97
XXII.	The Inclined Plane	102
XXIII.	Law of Machines — Perpetual Motion	106
XXIV.	Review of Machines	108

PART IV.— PRESSURE OF LIQUIDS AND GASES.

LESSON.		PAGE.
XXV.	Communicating Vessels — Hydraulic Press	111
XXVI.	Downward Pressure of Liquids — Buoyancy.	115
XXVII.	Specific Gravity	120
XXVIII.	Hydrodynamics	123
XXIX.	Aerostatics and Aerodynamics	126
XXX.	The Barometer	134
XXXI.	The Air Pump	138
XXXII.	Common Pump	145
XXXIII.	Force Pump	148
XXXIV.	The Siphon	153
XXXV.	Review of Liquids and Gases	157

PART V. — MAGNETISM.

XXXVI.	Magnetism and Magnetic Attraction	162

PART VI.— STATICAL ELECTRICITY.

XXXVII.	Electric Attraction	172
XXXVIII.	Electric Attraction and Repulsion	177
XXXIX.	Methods of Electrification — Contact — Induction — Electrical Machines	182

PART VII.— CURRENT ELECTRICITY.

XL.	Chemical Electricity	192
XLI.	Electrical Units	195
XLII.	Electro-Magnet — Electro-Magnetic Telegraph — Electric Bell	197
XLIII.	Lighting and Heating Effects of Electricity — Electro-Magnetic Induction	205
XLIV.	Chemical Effects of Electricity	215
XLV.	X-Rays	217
XLVI.	Review of Magnetism and Electricity	220

PART VIII.— SOUND.

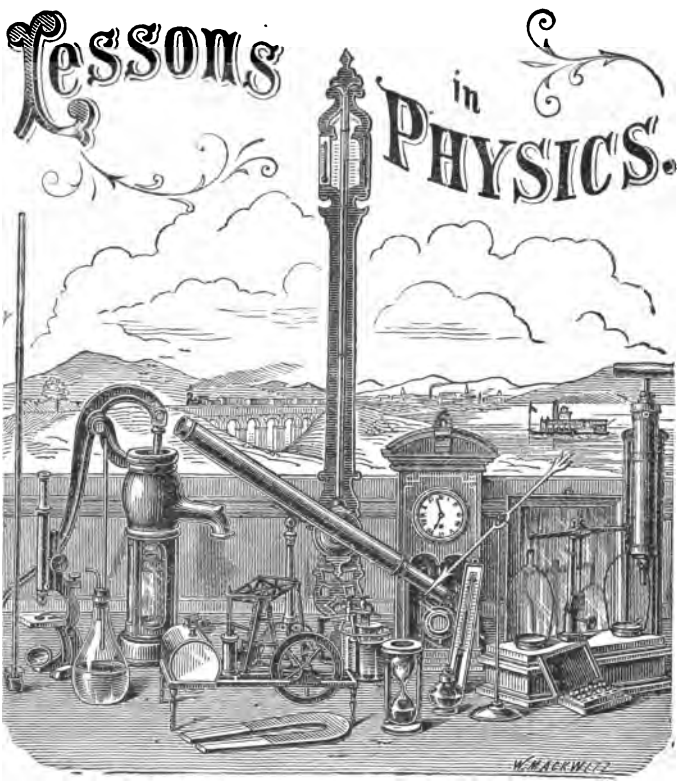
LESSON.		PAGE.
XLVII.	Sound	222
XLVIII.	Interference and Reflection of Sound	228
XLIX.	Oscillating Strings, Rods and Plates	230
L.	Wind Instruments — Phonograph	236

PART IX.— HEAT.

LI.	Heat — Sources — Conduction — Convection — Radiation	239
LII.	Expansion	247
LIII.	Melting — Boiling — Heat Units	251
LIV.	Evaporation — Fog — Clouds — Rain	254
LV.	Thermometer	258
LVI.	Thermometer Compared with Barometer	260
LVII.	The Atmospheric Engine	263
LVIII.	The Steam Engine	269
LIX.	Review of Sound and Heat	276

PART X.— LIGHT.

LX.	Nature of Light	281
LXI.	Reflection of Light	282
LXII.	Formation of Images by Curved Mirrors	287
LXIII.	Visible Direction — Refraction	296
LXIV.	Prisms and Lenses	301
LXV.	Color	311
LXVI.	Spectrum Analysis	317
LXVII.	Polarization of Light	321
LXVIII.	Optical Instruments	323
LXIX.	Review of Light	331
	Appendix	335
	Index	369



1, Barometer; 2, Microscope; 3, Heron's Fountain; 4, Pump; 5, Steam-Engine; 6, Magnet; 7, Telescope; 8, Barometer; 9, Galvanic Battery; 10, Hour-Glass; 11, Clock; 12, Thermometer; 13, Spirit-Lamp; 14, Magnetic Needle; 15, Mirror; 16, Balance; 17, Weights; 18, Pump.

LESSONS IN PHYSICS.

PART I. — MATTER AND MOTION.

LESSON I.

PROPERTIES OF MATTER.

Matter is anything that occupies space, or that has length, breadth and depth. Matter impresses itself upon us in different ways; it is from them that we derive our ideas of the *properties* of matter.

Distinct and limited portions of matter are called *bodies*. The earth, a pebble, air, a raindrop, are examples of bodies.

The essential properties of matter are *Extent* and *Impenetrability*. We are unable to conceive of a body that does not occupy a portion of universal space, that is, of a body without *extent*. Extent, therefore, is a property essential to all bodies. All bodies have three dimensions: C length, breadth and depth.

In addition to extent, every body has the property of excluding all other bodies from the place it

occupies. This is the second essential property of matter; it is commonly called *Impenetrability*. A nail, for example, can be driven into a board; as it passes into the wood, however, it must displace the particles of wood which are in its way; in other words, the nail can occupy no space in the board unless the particles of wood are first removed from this space. Shadows have neither depth nor impenetrability; hence they are not bodies.

1st Experiment.— To show the impenetrability of air, hold a glass funnel with its broad opening in the water so that only the edge is under water. Keep its tube closed with the finger, and press it gently downward. The confined air will permit only a very little of the water to enter; the air cannot escape, and therefore maintains its place to the exclusion of the water. Now remove the finger; the water will rise in the funnel because the air now can escape. Cement a funnel (with a fine tube) into the neck of a flask, and pour water or any other liquid into it slowly. A little of the liquid will enter the flask at first; immediately after, the liquid will fill the funnel but does not enter the flask, because, there being no escape for the air, the air maintains its place.

The most noteworthy general properties of matter are: Divisibility, Compressibility and Expansibility; Porosity; Inertia; Cohesion and Adhesion;

Elasticity; Hardness; Brittleness; Ductility and Malleability.

Divisibility.—By means of a cutting, filing or crushing instrument bodies can be divided into very small portions; and every small portion so obtained can again be subdivided a number of times until finally the portions obtained become so minute as to make it impossible to further subdivide them by mechanical means. But in this case they may be still further divided by the use of a solvent. Thus so small a quantity as a grain of indigo or carmine dissolved in water will give color to a large volume of water. The particles of the grain are distributed in such a manner as to pervade every drop of water; for if a single drop in the colored water were left free of coloring substance, it would appear colorless within the colored liquid and therefore be distinctly visible. Another agency for dividing bodies is heat.

In the case of metals the divisibility of matter has been carried exceedingly far. Wollaston obtained platinum wire $\frac{1}{300000}$ of an inch in diameter, made by drawing out silver-covered platinum wire very fine, and then removing the silver by the aid of nitric acid, which dissolves silver but does not affect the platinum. Gold has been beaten into leaves 250,000 of which if put together make up a height of only one centimeter. Gilded silver wire

can be drawn out so fine, that the film of gold upon it is only $\frac{1}{800000}$ of a millimeter thick; yet the gold appears continuous under the microscope, and if the thread be immersed in nitric acid, the gold will resist the action of the acid and protect the silver within. A grain of musk lying upon a balanced scale, will fill a large apartment with its odor for a long time. The odor is due to particles of musk in the state of vapor, which pervade the air of the room; yet at the end of a year or even a longer time, the scale will still be found balanced, showing that the musk that had meanwhile diffused itself into the air, had no appreciable weight.

Matter then can be divided into extremely minute particles. For this reason — and also for another reason which is beyond the scope of this work — matter has been thought to be composed of extremely minute particles, which are conceived to be indivisible and unchangeable, and which are called *atoms*. When two or more atoms unite with each other chemically, they form a *molecule*. We speak, for example, of an atom of hydrogen, or an atom of oxygen, but when two atoms of hydrogen unite chemically with an atom of oxygen, we speak of a *molecule* of water that has been formed. This molecule of water can again be decomposed into its constituents of hydrogen and oxygen, by the action of the electric current. Atoms as well as molecules are so exceedingly minute as to be invisible even

under the most powerful microscope, nor is anything known concerning their form or shape; in fact their very existence is a mere hypothesis. The molecules composing a body, moreover, are said not to be in contact with each other, but to be separated by, relatively speaking, a considerable space. The space separating these atoms and molecules is not empty, but, it is supposed, that they are filled with a material offering no resistance to the to-and-fro motion which the atoms and molecules undergo.

We may define the molecule of any substance as the *smallest portion of that substance which exists by itself*, and the atom as the *smallest portion of any element which exists even in combination.* An atom, therefore, is of one kind of matter only. A molecule is a group of atoms bound together.

LESSON II.

PROPERTIES OF MATTER — (*Continued*).

Compressibility and Expansibility of Bodies.— A sponge may be compressed into one-tenth its ordinary volume. An iron bar is denser, that is, occupies a smaller space after it is hammered. By means of the Piezometer, an apparatus invented by Oersted, water can be compressed into a slightly smaller space. Where an empty tumbler is held inverted in water, the air inside is compressed in direct proportion to the vertical height of water above it.

A sufficient increase in pressure, then, will sensibly diminish the volume of bodies. Gases are more readily compressed than solids, and, in general, solids more readily than liquids.

There are two agents that can be employed to compress bodies, viz., one, mechanical force, and two, cold, that is, the absence of the amount of heat that keeps a body in its normal volume. The liquid in any thermometer is an illustration of the reduction of volume by cold.

The volume of all bodies expands by heat and contracts by cold. A metallic ball, which when

cold passes through a metallic ring, will, if heated, be larger, and may consequently pass no longer through the ring. But as soon as cooled down again to the ordinary temperature, it will pass through the ring again, because on cooling it has contracted. The expansibility of air may be shown by means of a bent tube closed at one end. Drop a very little mercury into the bend of the tube; then gently heat the confined portion of the air, the mercury will commence to move toward the open end of the tube, because the confined air expands. If the closed end of the bent tube were a bulb, the mere heat of the hand applied to the bulb suffices to move the mercury. The expansibility of liquids by heat may be illustrated by the fluid in a thermometer.

Gases are more expansible than liquids; and liquids more than solids.

Porosity.— A sponge, a pumice-stone, or a piece of bread, shows accidental vacant spaces or interstices between its particles. These spaces are called *sensible pores*. They must not be confounded with *physical* or molecular pores, which are spaces between the molecules of bodies, so exceedingly minute as not to be rendered visible by the highest known magnifying power. It is the existence of this kind of pores to which the term "porosity" refers.

INERTIA — *Familiar Facts.*— A body at rest can not of its own accord put itself in motion. A stone on the ground, for example, will remain there forever unless disturbed by some action from without.

I. *Bodies at rest tend to remain at rest.*

A body in motion can not of its own accord change or stop its motion. A ball rolling on the ground, for example, will roll on forever unless arrested by some impediment such as friction.

II. *Bodies in motion tend to remain in motion.*

Principles I. and II. form what is called the *Law of Inertia*, viz. :—

All bodies tend to remain in their state of rest or motion as the case may be.

2D EXPERIMENT.— **Place a small** card on the mouth of a bottle or jar, and on the card put a small coin. If now the card be snapped off slowly, both card and coin move on together; but if the card be snapped off quickly it will move on alone and the coin will drop into the bottle or jar beneath. The reason of that is, the start of the card was so sudden and rapid as not to be communicated to the coin.

Familiar Facts.— (1.) Persons standing in a street car not in motion, are at rest. If now the car starts abruptly, these persons are apparently

thrown *backward;* but in reality they remain at rest for a moment, while their feet suddenly start onward with the car.

(2.) If a bowl filled with water, and at rest, be suddenly moved sideways, some of the water will still remain where it was before and consequently "flow over," that is, fall toward the ground.

(3.) A rifle ball shot through a pane of glass, merely makes a round hole in the glass. The ball moves so rapidly that it thrusts out all the glass on its way, before the glass around it receives sufficient motion to break.

(4.) A board freely suspended by a cord, will scarcely move when pierced by a bullet.

In the succeeding familiar facts (5–10) it is attempted to show the inertia of moving bodies:—

(5.) Persons standing in a street car in motion are themselves in a state of motion, the same as the car. If now the car is suddenly stopped, these persons are apparently thrown *forward;* in reality they remain in motion for a moment while their feet suddenly stop.

(6.) If a bowl filled with water, after being moved horizontally, be suddenly brought to rest, some of the water will still move on and consequently pass over the edge of the vessel.

(7.) When the handle of a hammer is rapidly struck endwise against a table, the head of the hammer continues moving after the handle has been stopped, which makes the handle fit more tightly.

(8.) A row-boat, by being pushed off the shore, receives a certain amount of motion which it keeps, and by virtue of which it continues to move on for a short time. If it be suddenly stopped, a person in it will be apparently thrown forward.

(9.) A grindstone, after being set in a state of motion and then left free to come to rest, revolves for a short time before it stops.

(10.) A locomotive once in motion can not be stopped suddenly; it will move for some time after the steam is shut off.

Bodies are set in motion by *forces*. They are brought to rest by *impediments* to motion.

A *force* is the cause of any change in the state of a body.

The chief *impediments* to motion are: 1. *Gravity;* when a stone is projected vertically, gravity draws it to the earth and thus prevents it flying away from the earth. 2. *Friction;* when a ball rolls on the ground, friction soon stops its motion. And 3. *Percussion;* when a ball is thrown against a wall, percussion stops its motion.

LESSON III.

PROPERTIES OF MATTER.—(*Continued*).

Cohesion.—If we stretch an India rubber strip it will lengthen, but unless it be torn or broken it will shorten again and return to its original size when the pulling force ceases. We find it a very difficult task to break an iron rod, and, in general, most solid bodies offer great resistance to any displacement of their parts. Cohesion is a property by virtue of which the molecules of a body cling together and resist separation. Let two pieces of lead be cut so that each presents a fresh, smooth surface; then if these surfaces are strongly pressed together, the two pieces will cohere. The same force of cohesion causes two perfectly polished glass plates to cling together. For this purpose they should be put together by sliding one over the other until both surfaces are in contact; in this way any air between them is expelled. Two such plates have been suspended horizontally under the exhausted receiver of an air-pump and weights attached to the lower plate, yet the plates will stay together, which shows that atmospheric pressure has nothing to do with the phenomenon.

Familiar Facts.—In order to cut meat, to whittle a stick, to sharpen pencils, to split logs,

to saw wood or to plane boards, we find it necessary to use instruments, such as a knife, an ax or a saw. It is difficult to break a piece of iron, because iron has a strong cohesive force. Rolled or hammered iron is much stronger than cast iron, because, by the process of rolling or hammering, its particles have been brought nearer together, and therefore cohere more firmly. The strength of our tools and building materials depends upon cohesive force. The supporting capacity of wire ropes, iron pillars, or steel rods is immense. A steel bar one inch square will support a weight of forty tons or more.

Although liquids offer very little resistance to a separation of their particles, still they possess cohesion. The cohesion among the particles of a liquid may be illustrated by the formation of drops.

3D EXPERIMENT. — **If the blade of a knife** be immersed in water and then withdrawn, some liquid will remain on the blade, and, if the blade be held pointing downward, form a drop of water which for a time remains suspended from the point of the blade. — Drops are also formed by water that is left unsupported in the air, such as rain, or the water of a jet. Also when a very little water is put on a red-hot metal plate. — A little mercury poured on a horizontal surface forms into drops.

To break a solid or to separate the particles of a liquid, we must overcome the force of cohesion.

Water in the form of ice has more cohesion than in the liquid state; but as steam it has no cohesion whatever. Solids have more cohesion than liquids; gases have none. Because by heating a solid we may liquefy it, and by continuing the heat we may convert it into gas, heat is said to destroy cohesion.

4TH EXPERIMENT.— **In a glass** vessel mix alcohol and water until the mixture has the specific gravity of petroleum. (This may be tested by putting minute drops of the oil into the mixture; the desired specific gravity has been obtained when they float within the mixture.) Then carefully introduce (by means of a pipette) a large quantity of the oil below the surface of the mixture. The oil will form a globule. For this experiment a square glass vessel is better than a cylindrical one, as it avoids the effects of refraction.

5TH EXPERIMENT.— **The cohesion** of liquids may also be shown by introducing into the oil spoken of in the experiment just described, two wire circles lying together; after withdrawal from the oil separate them from each other slowly, and a hollow cylindric film of oil will be produced. In a similar way, a hollow cube of oil may be produced by immersing a wire cube, that is, twelve short wires soldered or bent together so as to form the edges of a cube.

LESSON IV.

PROPERTIES OF MATTER.— (*Continued*).

Adhesion.— This term is applied to the clinging together of particles of bodies that are of different substances; also to the clinging together of the surfaces of bodies. The cohesion between the surfaces of the lead and that between the surfaces of the glass just mentioned is frequently called adhesion. Cohesion and adhesion are different terms for the same molecular force. Thus we speak of the *cohesion* between the particles of a rock, of a piece of wood, or of a drop of oil; and of the *adhesion* between ink and paper, or paint and wood.

Adhesion is the attraction between the surfaces of bodies in contact with each other.

Application.— All gilding, painting, whitewashing, cementing, varnishing, gluing, writing, soldering, coating of looking-glasses, plating, etc., etc. Soot adheres to the chimney; dust to the ceiling; chalk, or fresh paint, to one's clothing.

6TH EXPERIMENT.— **Immerse a clean glass plate** partly in water, some of the water will be seen to rise on both sides of the plate. Evidently the

adhesive force between the glass and the water is greater than the cohesive force of the water. Were it not so, the water would not rise. Now immerse another glass plate near the first and not parallel to it (Fig. 1). Water will rise between them, and the form of its surface will be concave. The nearer the glass plates are brought to each other the higher will the water rise between them. This is natural, for the quantity of water between them is in this case very small; and the cohesive force of the water, therefore, easily overcome by the adhesive force. If a glass tube be immersed (see Fig. 2) the water will rise still higher, because here is a small quantity of water, surrounded on all sides by glass, and the force of adhesion is, therefore, comparatively of greater effect.*

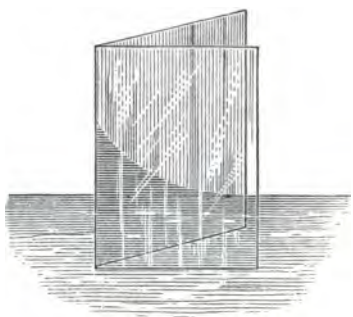


FIG. 1.

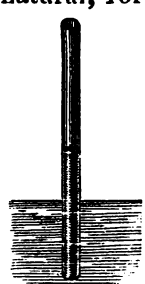


FIG. 2.

Capillary tubes (from the Latin, *capillus*, a hair), are open tubes having a very narrow bore.

* But the reverse of all these phenomena takes place — that is, water is always depressed about glass surfaces, if these are greased. Grease has no attraction for water; the water, consequently, is left free to obey its cohesive force, and falls below the level of the liquid surrounding the tube. In this case we have *capillary depression.*

When such a tube comes in contact with a liquid which is capable of moistening it, the liquid is compelled to rise in it. The finer the bore of the tube, the higher will the liquid ascend. In a tube $\frac{1}{100}$ of an inch in diameter water will rise over five inches.

7TH EXPERIMENT.—**Place a fresh** lamp wick in a tumbler containing petroleum, part of the wick bending over the edge of the tumbler. The oil will rise in the capillary tubes of the wick, and fall in drops from the overhanging end of the wick.

Capillary attraction is the result of adhesion operating between solid and liquid bodies.

Application.— Sponge, blotting-paper. Eggs and meat may be kept fresh in sand or pulverized charcoal, these two substances containing capillary tubes which absorb any moisture that would otherwise affect the eggs or the meat. Lamp wicks also contain capillary tubes; they suck up the oil in the lamp. Sugar also has capillary tubes. Grease spots on the floor may be removed by laying earth upon them. Our clothes become wet from the rain. In short, *almost everything about us is filled with fine capillary tubes.*

LESSON V.

PROPERTIES OF MATTER — (*Continued*).

The Three States of Matter. — Bodies occur in the solid, liquid or aeriform state. A substance may occur in the three states, as *e. g.*, ice, water, and water vapor. Generally speaking, solids and liquids have an unchangeable volume; solids have a shape or figure of their own, which liquids and gases have not. Liquids have the shape of the vessels containing them. Liquids have but little cohesion.

Aeriform Bodies, or gases, have neither cohesion nor unchangeable volume nor a shape of their own. The volume they occupy depends upon the external pressure to which they are subjected. A body of air can easily be compressed into $\frac{1}{2}$, $\frac{1}{4}$, or $\frac{1}{10}$ of its former volume; with the same facility it can expand, and fill twice, four times, or ten times its former volume if placed in a vacuum of corresponding size. Gases have a constant tendency to expand.

The distinctions just mentioned, regarding the three states of matter, are based upon the supposition that the molecules of solids are in a nearly fixed position with reference to each other, while among the molecules of liquids there is great freedom of

motion, and that the atoms of aeriform bodies tend to separate from each other as far as is possible. Of all bodies, then, solids have most cohesion; liquids have but very little, and gases none at all.

ELASTICITY — 8TH EXPERIMENT.— **Take an ivory ball; press it with your hand upon a slab of marble that has been blackened over a lamp. The ball will show a black spot about as large as a pin's head. Now lay the slab upon the floor, stand on a table, and let the ball drop upon the slab from a considerable height. The ball will then have a black spot much larger than before. Although of a hard substance, the ball is flattened when it strikes the slab, and in resuming its former shape, it rebounds. The black spot indicates the extent to which the ball came in contact with the slab.**

If the string of a cross-bow be drawn, and it is then let go, the arrow placed before it flies off with astonishing rapidity. "How is it," may we ask, "that a string can obtain such great force?" If a piece of India-rubber be doubled between the fingers, it will become straight again when the pressure is removed. After pressing a steel pen gently against the thumb nail to try its writing qualities, it recovers its former shape.

Springs, ivory, or India-rubber, and many other bodies, have the property of recovering their former

figure when the force which distorts them ceases to act, provided the force be not too great.

This property is called *Elasticity;* and all such bodies show readily that they are *elastic.* All bodies are more or less elastic; some substances, however, such as lead or clay, do not readily exhibit their elasticity, and were formerly called *inelastic.*

Applications of Elasticity. — 1. *To produce motion:* Watch-springs; springs in watch cases, boxes, and carriage-lanterns; the ballista of the ancients; the cross-bow; locks, and triggers. 2. *To counteract concussion:* Wagon-springs; packing glass ware in hay or straw; springs in mattresses, sofas, chairs and etui-cases. 3. *To cause close contact or pressure:* Springs in pocket-inkstands; printers' cylinders; some kinds of pen-holders. 4. *For weighing:* Spring-balances.

Hardness — Softness. — An ivory ball is elastic and hard; an India-rubber ball is elastic and soft. If we take a glass rod and try to bend it as much as a steel rod can be bent, it will break. The steel rod is hard and elastic, while the glass rod is hard but much less elastic. Moist clay is soft, and has very little elasticity.

All this shows that no intimate connection exists between elasticity, and hardness or softness. A

body is *hard*, when a great force is required to scratch it or to displace its particles; a body is *soft*, when its particles can be displaced by a slight force.

Brittleness. — To break a steel rod requires a great force; while a pane of glass can be broken by a slight blow. Every substance can be broken, but the degree of force required is not the same for each. Glass or chalk is brittle, that is, easily broken. The property of being easily broken or fractured, is called *brittleness*.

Ductility. — Instead of breaking the steel rod, let us endeavor to stretch it; we find that only by a very great force can it be drawn out into a long wire. A narrow glass tube can be drawn out very thin by the heat of a flame. Bodies which can be drawn out into a thread or wire are ductile; this property is called *ductility*.

The following metals stand in the order of their ductility: Platinum, silver, iron, copper, gold, tin, and lead.

Malleability. — Many substances, such as iron, copper, brass, gold, or silver, besides being ductile, can be hammered into sheets; hence they are called *malleable*. Some substances, as lead for example, are malleable without being ductile. Gold, the most malleable metal, has been hammered out into

leaves each only $\frac{1}{300000}$ of an inch thick. The property enabling us to roll or hammer a substance into sheets, is called *Malleability*.

From this lesson we may learn that when the force which displaces the parts of a body is within certain limits, the body may exhibit elasticity; if beyond certain limits, it exhibits the properties of brittleness, ductility or malleability. The force acting in such a case is called the *Stress;* the change in form produced during its action is the *Strain.* Substances, that do not entirely recover their original form, when *strained*, are said to be *imperfectly* elastic, while those which completely recover their original form are called *perfectly* elastic. The amount or limit below which a substance is perfectly elastic is called *limit of elasticity.* Brittle substances can be strained nearly to the breaking point without passing this limit. Malleable and ductile materials generally reach this limit at much less strain than is required to break them.

LESSON VI.

PROPERTIES OF MATTER.—(*Continued*).

Elasticity of Fluids.— The term "Fluid" comprises both liquids and gases. Gases possess compressibility and elasticity in a far greater degree than liquids or solids. The elasticity of gases is also called *tension* or *pressure.*

9TH EXPERIMENT.— **If we immerse an inverted tumbler** perpendicularly in water, only a very little of the water will enter the tumbler, and the air in the tumbler will be compressed. If the vessel is pressed down still farther, a little more water enters it, but it will never be entirely filled with water, because it contains air. A cork previously placed in the tumbler, will show the position of the water level inside. (See Fig. 3.) Air maintains its place like every other body; hence it shuts out the water almost completely. But if you withdraw the hand which presses the tumbler down, the tumbler will instantly rise. The air in the glass was *compressed* and recovered its previous space, because *air is elastic.*

FIG. 3.

10TH EXPERIMENT.— **Immerse a glass funnel** in the place of a tumbler; and if inverted with the mouth downward, the upper end being closed with the thumb, the air in the funnel is compressed. As the thumb is removed, however, water rushes into the funnel, because, in this case, the air can pass out.

11TH EXPERIMENT.— **Cement a funnel** into the neck of a small bottle, and pour water into it. Only a little water will enter at first; but subsequently not a drop will get in, as there is no escape for the air. For as the water is poured into the funnel, it forces the air in the tube of the funnel into the bottle. The air in the bottle has now no outlet and, consequently, no water can enter.

12TH EXPERIMENT.— **A good illustration** of the expansive force of air is obtained by a "Heron's Fountain." Take a cork which fits into a bottle, and perforate it with a round file. The hole should be made so as to admit with difficulty a glass tube, which is now pushed through the cork. The tube should have a very fine opening above. This being done, fill the bottle about half with water and close it with the cork. Then drive the glass tube farther down, until it nearly reaches the bottom of the bottle. The bottle now contains air in its upper

FIG. 4.

part and water in its lower. On blowing more air into the tube, the air will ascend through the water and collect in the space above. But now the air over the water is compressed, and its expansive power forces the water upward through the tube. The inventor of this apparatus was Hero, a philosopher, who died in Alexandria, over two thousand years ago.

An *application* of this property of air is the air chamber, used in connection with pumps; the toy known as the pop-gun; the condensing pump, an apparatus for compressing air or any other gas; the small pump used by plumbers for testing and cleaning gas pipes; the air-gun which consists of a charged receiver, connected to a gun barrel. After fitting a bullet to the bottom of the barrel, a trigger turns the stop-cock connected to the charged receiver and the condensed air rushes out with great force. This principle is also used in ventilating mines, in supplying air to blast furnaces, in the air brakes used in railway trains, and so forth.

LESSON VII.

MOTION.

Familiar Facts.— A carriage passing by a house changes position at every instant; it is therefore said to be in motion. But a carriage standing by the roadside keeps itself, generally speaking, in the same position as regards surrounding objects; it is therefore said to be at rest. When a brakeman upon a railway train in motion runs from the front of the train towards the rear exactly as fast as the cars are moving forward, he appears to persons on the train to be in a state of motion; but to persons standing on the ground he appears to be stationary, because his distance from objects on the ground remains the same. A person in a canal-boat which is gliding along in a dark night, may think it is in a state of profound rest, because, although he and the boat are in motion, he perceives no change in the distance between the boat and surrounding objects.

The instances here given show our ideas about rest and motion to be based upon comparison.

Rest.— The earth has two motions: it turns upon its axis and revolves around the sun. All terrestrial objects participate in these motions. The other

planets, the comets and the sun also, are in continuous motion; no instance of absolute rest is known; we are even unable to define the term "rest." On our planet rest may, in one sense, mean the state a body is in when it has only those motions that the earth possesses, as is the case with buildings free from local disturbances; in another sense, rest may be said to be that state in which, generally speaking, a body keeps at the same distance from objects immediately around it.

Rest is relative in its character. Absolute rest is unknown, for we know of no fixed point in space.

Motion.— The normal state then of all bodies is motion. There are good reasons for believing that even the smallest particles of every substance are in rapid motion among themselves. A body is in motion when it does not keep its position with reference to objects around it. Motion is change of place. The characteristics of motion are: 1, *Path;* 2, *Space;* 3, *Direction.*

Path.— The path of a motion is the line described by a moving body. It may be straight or curved. Motion in a straight line is also called rectilinear motion; and motion in a curved line, curvilinear.

Space.— Every body occupies a portion of universal space. The portion of universal space which

a body on our globe occupies with reference to the earth as a whole, is its position or place. A moving body occupies successive places in successive times; the entire number of places so occupied forms the length of path, or the space passed over by the body. Space is indicated by *s;* it is measured by the different standards of length adopted by the nations of the earth.

Direction.— A mariner climbing a mast, a person ascending an inclined plane or walking over level road, furnish instances of direction. The direction of a moving body is frequently indicated by the angle which its path forms with some line taken as a standard. Thus the direction of a body falling freely through space is that of an angle of 90° from the horizontal. When speaking of a cannon ball projected at an angle of 33°, this number indicates the length of arc between the horizontal and the path in which the missile was projected.

Time.— Time is measured by motion through space. Whenever a body passes over successive lengths or portions of space, it must occupy successive lengths, or portions of time, however small these portions be. Time is usually indicated by *t;* it generally is measured by a unit such as the second of mean solar time.

Uniform Motion takes place when equal lengths of space are passed over in equal lengths of time.

The rotation of the earth and the transmission of light are instances of uniform motion.

Accelerated Motion.— A railway train just starting on its journey passes during the second second of time over a greater length of space than in the first second after starting; and in the third second the space described is greater still. In a case like this the motion is not uniform; for in equal units of time unequal units of space are passed over; and as the spaces increase while the times remain the same, this kind of motion is called accelerated. Accelerated motion is that motion in which increasing lengths of space are passed over in equal lengths of time. If the acceleration occurs in a fixed ratio, the motion is uniformly accelerated. A stone falling freely through space is an instance of uniformly accelerated motion.

(2.) *Retarded Motion.*— When a railway train approaches its place of destination, its speed diminishes gradually, the train finally stops. In the first second in which it ran with diminished speed, it passed over shorter lengths of space than in the previous second in which it had uniform motion. In the next second it passed over a shorter path; in the third second over a path still shorter than the preceding; in the fourth second over less path than during the third second, and so on until it stopped. This kind of motion is called retarded

motion, because decreasing lengths of path are passed over in equal lengths of time.

Periodic Motion.— The oscillation of a pendulum, or the revolution of the earth around the sun, are periodic motions, because, while they contain accelerated and retarded motion combined, they recur in regular intervals of time.

Velocity.— A railway train moving over a great length of path in a short time, has a great velocity when compared with one moving over the same space in a longer time. Velocity is the degree of quickness with which a body moves over a certain space.

Uniform velocity is measured by the space described in a unit of time; the unit is generally a second. Accelerated or retarded velocity is measured by the space the moving body would have described had it continued its motion unaltered during one second. A rifle ball, for example, moving at the rate of 1,200 feet a second, may strike before the second in which it started has expired; but its velocity is nevertheless said to be 1,200 feet a second, because if it had continued moving for one second it would have described a space of 1,200 feet. Velocity is usually indicated by v.

LESSON VIII.

THE LAWS OF MOTION.

1ST LAW — *Permanent, Uniform Motion in a Straight Line.*— Motion being the normal state of bodies, a body once in motion, and free from the action of external forces, will tend to move permanently with uniform velocity in a straight line.

If friction and gravity could be removed entirely, and if no other heavenly body existed except the earth, any object projected into space would continue moving in a straight line, with unchanged velocity. Such motion would be an instance of permanent, uniform motion. The nearest approach to it is the earth's revolution around the sun. The earth probably moves through a resisting medium in space; but the dimensions of her orbit are not known to have changed, and if they vary at all, they vary only by a small amount in long series of years. The nearest approach to motion in a straight line is the fall of a body dropping freely from a point in still air.

Motion is indestructible. When the motion of a body is stopped, it is not therefore destroyed, but continues to exist as motion of some other kind, as heat, or light, or both together.

From what has been stated in the lesson on Inertia (page 8, Lesson II), it is clear, that a body at rest remains at rest until it is disturbed by some force; and a body in motion remains in motion until set at rest by some external force. If no such force be applied, the original motion remains *unaltered, rectilinear, and permanent.*

FIRST LAW OF MOTION.— *A body in the state of rest or motion can not of its own accord change its state. If the body has only one motion, and is undisturbed by other motions, this motion is permanent, rectilinear, and uniform.*

This law supposes a state of affairs which never occurs upon our globe.

SECOND LAW OF MOTION.— I. *Two or more uniform motions acting upon a body at the same time and in the same straight line, produce the result of a single motion. If those motions have the same direction the velocity of this single motion is equal to the* SUM *of their velocities; if they have opposite directions, the velocity of this single motion is equal to the* DIFFERENCE *of their velocities.*

A ball lying on the deck of a ship at anchor, is at rest as regards the ship and the earth. It would be so considered by observers on the shore or on board. If the ship be moving, the ball will move with it, and to an observer on board the ball will still seem

to be at rest; whereas to a person standing on shore it will now appear to be in motion.

If the vessel moves at the rate of 10 feet a second and the ball be impelled at the same rate in the same direction, its velocity will be $10 + 10 = 20$ feet. But compared with the velocity of the vessel, that of the ball is only 10 feet.

If the ball be impelled at the same rate in a direction opposite to that of the ship, its velocity $= 10 - 10 = 0$; that is, an observer on shore will see it at rest. A person on board the vessel will behold it in an apparently receding motion, just as he would any fixed point on the shore.

The ball obeys the motion imparted to it regardless whether the ship is moving or not; and the ship moved onward regardless of the ball being at rest or in motion; and the motion of both the vessel and the ball took place regardless of the fact, that these bodies shared two other motions, viz.: the diurnal rotation of the earth and its revolution round the sun.

II. *Two rectilinear uniform motions not in the same straight line, acting upon a body.*

If a body is subjected at every instant of time to two motions not in the same straight line, it can not obey one of these motions first and the other after-

wards, nor one more than the other, but it must obey both fully and at the same time. It will then have a compound or *resultant motion.*

A familiar illustration of *resultant motion* is the case of a ferryman crossing a river in a row-boat. The action of the oars impels his boat (Fig. 5), in the direction *A B*, the action of the current in the direction *A C*. Supposing the motion from *A* to *B* to require five minutes, and that from *A* to *C* (or *B* to *D*) five minutes; then will the two motions if taking place at the same time, cause the boat to pass from *A* to *D* in *five minutes.* That is, the boat will land at *D* as if it had first passed from *A* to *B* by the force of the oars, and then from *B* to *D*, by the force of the current. In order to demonstrate that the boat actually describes the path *A D* in five minutes, lay off *A B* and *A C* each in five equal parts, representing minutes. The action of motion *A B* in the first minute tends to impel the boat from *A* to 1, but in the same minute motion *A C* tends to impel it from *A* to 1′. Now as both forces are acting at the same time the boat will go neither toward B.

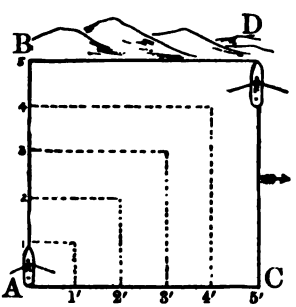


FIG. 5.
Second Law of Motion.
Ferryman Crossing River.

nor C. but will take a course midway between these two forces, that is it will be impelled toward D.

Every Motion Independent.— When a person leaps a foot vertically upward, he alights on the place whence he leaped, although the surface of the ground under him has moved meanwhile. The reason of that is, that he always has the same velocity as the earth, whether he is moving or not. Suppose the person to be at the equator and that his leap took him one second. During this second, the ground at the equator rotated through 1,525 feet of space. Now, the person participated in this motion of earth whether he leaped or not, if he had not participated, he would have alighted 1,525 feet behind his starting-point.—A ball thrown up vertically on board a vessel in motion returns to its starting point, for in the time that it rises through the air, it still keeps the onward velocity of the boat and that of the earth.

THE SECOND LAW OF MOTION may be expressed as follows:—

Two or more motions jointly acting upon a body, produce the same result as if each acted upon the body separately.

Instead of the term "Motions" that of "Forces" is often used.

LESSON IX.

THIRD LAW OF MOTION.

Force.— If a stone be left unsupported, it drops to the ground. Its downward motion, however, is not the cause but merely a condition of its fall. The actual cause of its fall is unknown, but is generally explained to be the earth's attraction. An arrow is projected from a cross-bow; what is the cause of its flight through the air? The answer is: the elasticity of the bow. For the elasticity of the bow gives the bowstring a motor (or motion-producing) power whenever the bow is bent.— A sailing craft is moved by wind; the cause of its motion is the pressure of the wind against the sail.

A multitude of such phenomena together with the results of centuries of experiments in physical science, prove beyond a doubt that every motion has a cause; and that every physical change or effect must have a physical cause. Physical causes are generally called forces. In a general way, forces are spoken of as "the unknown causes of known effects," because they are known to us only by the effects that they produce.

Force may be defined as *the cause of any change in the state or condition of bodies, or of any effect whatsoever produced upon them.*

Action and reaction.

13TH EXPERIMENT.— **If the hook** (at the free end of the spiral spring) of a spring-balance be pulled with the hand, the spring will be elongated, and the amount of elongation corresponds to the amount of pull. If, when we attach a ten-pound weight to the hook, the same amount of elongation is obtained as before, then the pulling force exerted by the hand was equal to a ten-pound pull.

But it is important for us to notice the fact that at the instant we remove the weight, the spring (which is supposed to be perfectly elastic) *recoiled* with a ten-pound pull; that is, the spring exerts a pull in the opposite direction, and this pull is equivalent to the stretching force.

An iron ball lying upon a table presses upon the table with its entire weight. This downward pressure of the ball compresses the portion of the table immediately under it, although the amount of the compression may be very slight; it causes the table to react against the ball. The ball thus receives back its own pressure. It impresses itself upon the table, and its pressure is equal to the reaction of

the table; were it not so, nothing would prevent the ball from sinking further.

The velocity of an arrow projected from a cross-bow is proportionate to the tension of the string. The tension of the string acts against the arrow, but the inertia of the arrow reacts against the string. These two actions are equal to each other, and opposite in direction. If the tension be diminished, the motion of the arrow is diminished; if the tension be increased, the motion of the arrow is increased.

If a man stands in the rear of a boat, Fig. 6, pressing with a pole against the bow in order to urge the boat onward, he presses with his feet against the rear of the boat and with his arms in opposite direction against the bow.

FIG. 6.
Action = Reaction.

This *action* in the forward direction is equal to the *reaction* of the rear of the boat; or, his action against the rear of the boat is equal to the reaction of the bow; consequently the action of his body in one direction is equal to the reaction of his body in the opposite direction; hence the boat will not move at all.

The velocity of a cannon ball is due to the formation of elastic gases which are confined within a narrow space. By their great expansive force they exert a pressure upon the ball, and continue to exert it until the ball has left the

cannon. But as they are shut in on all sides, they exert the same pressure in all directions; that is, their action against the ball operates also upon the remaining parts. We speak of their "action" upon the ball, and of their "reaction" upon the gun. This reaction manifests itself as the recoil of the gun, and takes place in a direction opposite to the motion of the ball. The heavier the cannon, the less its recoil — (the weight of the ball remaining the same); yet, action and reaction are equal to each other here also, for calculations show, that the product of the weight of the ball into its velocity is equal to the product of the weight of the cannon (including the carriage) into its velocity. The recoil may be apparently avoided by walling up the cannon so as to make it immovable. In this case, instead of being confined to the cannon, the recoil is communicated to the earth; that is, both cannon and earth will now move together, but on account of the immense mass of the earth the amount of their motion will be inconceivably small.

Propulsion by water or air in motion. — It might seem that without any motor power a boat on a river would not move at all, because the action of the current is opposed by its equivalent, the reaction of the boat. But if the boat did not move with the water, the pressure of the water against the side of the boat facing the current would be greater than that against the opposite side; and the difference

between these two pressures against the boat would tend to move the boat; and the motion of the boat would continue to increase by the action of the current, until the two pressures became equal to each other. At this moment the boat will move with the current. The ball referred to above was carried through space during the earth's revolution in her orbit, notwithstanding downward pressure on the table. And would it not have exerted the same amount of pressure if carried by a person running at a rapid rate? So the boat travels with the current because the water happens to be in motion while it sustains the boat. If the water suddenly stopped flowing, the boat would stop also, the other conditions, however, would remain the same as before. To move the boat in still water we may use a paddle, which then becomes a part of the boat. The paddle is made the agent of a force acting against the water; the water reacts, that is it exerts pressure against the paddle and consequently against the entire boat; it is this pressure or reaction, that causes the boat to move. If we diminish the power at the paddle, the motion of the boat will also be diminished; and if the power ceases acting, the motion of the boat will also cease.

THE THIRD LAW OF MOTION is usually expressed as follows:—

Action is equal to reaction, and opposite to it in direction.

To seize the full meaning of this important law, a few additional phenomena should be studied.

A man may be able to leap over a fence, but he cannot lift himself over it by pulling at his boot-straps. This may be explained as follows: Let the weight of his body = 150 lbs. and let him lift with each hand 75 lbs. from the ground. The pressure of his feet upon the ground will then consist

1st, of his own weight.....=150 lbs.
2d, of the gravity of the two weights $2 \times 75 = 150$ lbs.

His downward pressure in all .....300 lbs.

but he lifts only 150 lbs. Now let him get into a narrow basket and try to lift the basket by the handles. The pressure of his feet upon the basket will then consist of

1st, his own weight..... 150 lbs.
2d, the reaction of his upward pull..... 150 lbs.

His downward pressure in all..... 300 lbs.

but as before he lifts only 150 lbs., that is, 75 lbs. at each ear of the basket. The two cases, therefore, are similar; he lacks each time an upward pressure of 150 lbs.

LESSON X.

REVIEW.

1. Matter is anything that occupies space, or that has length, breadth and depth.

2. Distinct and limited portions of matter are called *bodies.*

3. The *essential* properties of matter are *Extent* and *Impenetrability.*

4. The most noteworthy *general* properties of matter are: 1. Divisibility. 2. Compressibility and Expansibility. 3. Porosity. 4. Inertia. 5. Cohesion and adhesion. 6. Elasticity. 7. Hardness. 8. Brittleness. 9. Ductility. 10. Malleability.

5. Divisibility is the property of matter according to which it can be divided into minute particles.

6. Compressibility and Expansibility are properties of matter according to which bodies may be compressed or expanded.

7. Porosity is a term referring to the existence of *sensible* and physical pores in bodies.

8. All bodies tend to remain in their state of rest or motion as the case may be.

9. The chief impediments to motion are: Gravity, Friction and Percussion.

10. Cohesion is a property by virtue of which the molecules of a body cling together and resist separation.

11. To break a solid or to separate the particles of a liquid we must overcome its force of cohesion.

12. Adhesion is the attraction between the surfaces of bodies in contact with each other.

13. Capillary attraction is the result of adhesion between liquids and narrow, so-called *capillary* tubes.

14. Bodies occur in the solid, liquid and aeriform state.

15. Aeriform bodies have neither cohesion, nor unchangeable volume, nor shape or figure of their own.

16. Springs, ivory, India-rubber, and many other bodies, have the property of recovering their former figure when the force which distorts them ceases to act, provided the force be not too great. This property is called Elasticity.

17. All bodies are more or less elastic.

18. Hardness is that property by which a body can not be scratched, nor its particles displaced, except by the application of great force.

19. Softness is the property by which the parts of a body can be scratched or displaced, if a slight force is applied.

20. Brittleness is the property by which a body is easily fractured.

21. Ductility is the property by which a body is readily drawn out into wire.

22. The following metals stand in the order of their ductility: platinum; silver; iron; copper; gold; tin, and lead.

23. Malleability is the property which enables us to hammer or roll a body into thin sheets.

24. Elasticity is displayed only when the force displacing the parts of a body is within certain limits.

25. When the force displacing the parts of a body is beyond certain limits, the body may exhibit brittleness, ductility, or malleability.

26. The term "Fluid" comprises both liquids and gases. Gases possess compressibility and

elasticity in a far greater degree than liquids or solids. The elasticity of gases is also called *tension* or *pressure*.

27. Ideas about rest and motion are based upon comparison.

28. The term *Rest* is relative in its character. Absolute rest is unknown to us. Know of no fixed point in space.

29. The normal state of all bodies is motion. Motion is change of place.

30. The characteristics of motion are path, space and direction.

31. The *path* of a motion is the line described by a moving body; the *space* is that portion of universal space which a moving body passes over. The *direction* of a moving body is frequently indicated by the angle which its path forms with some line taken as a standard.

32. Uniform motion takes place when equal lengths of space are passed over in equal lengths of time.

33. Accelerated motion takes place when increasing lengths of space are passed over in equal lengths of time.

34. Retarded motion takes place when decreasing lengths of space are passed over in equal lengths of time.

35. Periodic motion takes place when accelerated and retarded motion occur combined in a body in regular intervals of time.

36. Velocity is the degree of quickness with which a body moves over a certain space.

37. First Law of Motion: A body in the state of rest or motion cannot of its own accord change its state. If the body has only one motion, and is undisturbed by other motions, this motion is permanent, rectilinear and uniform.

38. Second Law of Motion: Two or more motions jointly acting upon a body produce the same result as if each acted upon the body separately.

39. Third Law of Motion: Action is equal to reaction, and opposite to it in direction.

PART II. — FORCE AND ENERGY.

LESSON XI.

FORCES.

Universal Gravitation is the most prominent and probably the most important force of nature. It was first explained by the genius of Sir Isaac Newton, in 1687, and is known to account for (1) the revolutions of the heavenly bodies, (2) the perturbations of the planetary orbits, and (3) the tides.

Mutual Attraction of the Sun and the Earth.— The sun and the earth attract each other. The two attractions are equal and opposite, which will be readily understood, if we imagine the sun cut up into 350,000 globes like the earth, grouped in a circle around the earth (that number being the mass of the sun if the mass of the earth be assumed as one). The earth will attract each of the 350,000 bodies, but each of these will also attract the earth and will do so in its own direction. If now the 350,000 globes be imagined collected together into one globe, this enormous mass will pull the earth with the same force, but in only one direction; and the earth will attract each unit of mass in the opposite direction.

In order to lift an object, a certain amount of muscular force is required with which to overcome

the downward pressure, or weight, of the object. If now the object be dropped, it will fall, until it is stopped by some resistance such as the floor or ground. This downward tendency of all bodies at the surface of the earth indicates that they will not rise of their own accord, and that there must be something which "attracts" or "pulls" them to the earth.

Familiar Facts.— Chalk, pencils, paper, pens, and other objects, often fall from the desk upon the floor. A stone thrown into water sinks to the bottom; a sign-board blown off by the storm falls upon the street; rain, snow, and hailstones descend from the clouds. Heavy rods are attached to maps and curtains, to draw them down. The weights of a clock move in a downward direction.

FIG. 7.

The facts given above may be comprised under the law: *All bodies fall, if unsupported.*

They seem to be *attracted* to the earth. The force that moves them to the earth, is called the Force of Gravity.

14TH EXPERIMENT.— **This stone is not supported** by the hand (Fig. 7), but it is suspended. What pre-

vents it from falling? The string. When you draw the stone a little to one side and then let it go, it will swing back and forth, and finally come to rest. When at rest the string indicates the direction in which an object would fall, if it were left free to fall. That direction is *vertical*. An illustration of it is the plumb-line used by carpenters and bricklayers.

The direction in which bodies fall when they are moved by the force of gravity alone, is vertical.

15TH EXPERIMENT.— **Place a large book upon the hand**; the hand will be pressed downward. If a small book be taken, the downward pressure is much less; and we conclude that the smaller book has less weight than the large one.

Familiar Facts.— A large stone presses itself into the ground. The weight of a heavy wagon makes deep ruts in a road.

The pressure which bodies exert when supported, or the pull which they exert when suspended, is called WEIGHT.

16TH EXPERIMENT. — **A rod or yardstick balanced** on the edge of the hand has equal weight on each side of the hand. The direction of the rod is horizontal. Now, let a crayon be suspended from each end of the rod; the rod will be horizontal, if both crayons have like weight. If a number of

crayons be suspended from one end of the rod, and a weight from the other, we have a crude form of the scale or balance.

A *balance* is an instrument for weighing. Pieces of iron, brass, or lead, are used as standards; they are called the weights. There are different kinds of balances; one consists of a delicately poised rod with a pan suspended from each end, one pan holding the weights, the other the substance to be weighed. Both pans exert downward *pull*. Another form consists of a delicately poised rod, but with the pans directly over its ends. Here the pans exert downward *pressure*. Then, there is the steelyard, and the spring balance.

Gravity attracts all substances alike. A mass of feathers weighing a pound contains precisely as much matter as a mass of lead weighing a pound; a pound of water is as heavy as a pound of iron.

The force of gravity resides in every particle of matter composing the earth. The force of gravity is that force by which (1) the earth draws all objects to itself and tends to keep them there; and (2) all the parts that constitute the earth are drawn toward each other.

The force of gravity is put to use in balances (the spring balance excepted), the plumb-line, clock-weights, hour-glasses.

Allow a weight (Fig. 7) suspended by a string, to dip in water. The surface of the water is *horizontal;* a vertical line makes a right angle with any horizontal at the same place. If a line makes a right angle with another, both lines are *perpendicular* to each other.

Horizontal means the direction maintained by the surface of a liquid at rest.

When two or more plumb-lines are held up not far away from each other, they appear to be parallel to each other. But when there is a considerable distance between them, they are not parallel to each other, because if sufficiently prolonged, they would meet at the center of the earth. A plumb-line at the foot of a mountain will not hang precisely vertical; but its lower end will incline a little toward the mountain because the mass of the bob will be sensibly attracted sidewise by that of the mountain. The amount of this inclination is very slight, but has been indirectly measured.

LESSON XII.

FALLING BODIES.

Falling Bodies.— The velocity and space passed over by bodies falling under the influence of gravity, are studied with less difficulty if we imagine that the bodies fall freely, that is, free from the resistance of the air; and that they fall to the surface of the earth from short distances, so that through these distances the intensity of gravity will be sensibly uniform.

Their Velocity.— Experiments show that in our latitude, and at the level of the ocean, a body that falls freely from a state of rest, is pulled down by gravity 32.1816 feet every second of its fall. This downward pull is indicated by g, and may for our purposes be assumed as 32 feet. It is also called the "acceleration" of gravity, because gravity accelerates — hastens — the descent of a falling body at the rate of 32 feet every second of fall.

The velocity acquired by freely falling bodies is equal to the product of their time of fall into g.

Formula (1) $v = gt$. (Galileo 1602.)

Hence	v	at the	end	of	the 3d	second	= 3.32 ft. =	96 ft.	a sec.
"	v	"	"	"	4th	"	= 4.32 ft. =	128 ft.	"
"	v	"	"	"	10th	"	= 10.32 ft. =	320 ft.	"
"	v	"	"	"	$4\frac{1}{2}$	"	= $4\frac{1}{2}$.32 ft. =	144 ft.	"
"	v	"	"	"	$\frac{1}{2}$	"	= $\frac{1}{2}$.32 ft. =	16 ft.	"

Space described during the first second.— At the end of the first second, a body falling under gravity

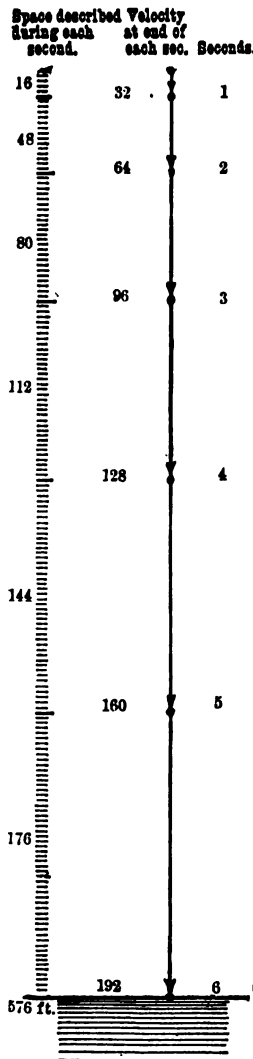


FIG. 8. Body falling freely under Gravity. — Time: 6 seconds — g = 32 feet.

has a velocity of 32 ft. a second, while at the start it has no velocity at all. Its v at the end of the first quarter of the second $= \frac{1}{4}.32$ ft. $= 8$ ft. a second; that is, with gravity suspended, the body would continue its downward passage with a uniform $v = 8$ ft. a second. At the close of the first half-second, its $v = \frac{1}{2}.32 = 16$ ft. a second; at the close of three-fourths of this second, its $v = \frac{3}{4}.32 = 24$ ft. a second, and finally, at the termination of the full second, the v of 32 ft. a second is obtained. Now with a starting velocity $= 0$ ft. and a final velocity $= 32$ ft. a body cannot pass through 32 ft. in the first second; although the body makes up by greater speed during the latter part of the second what it

lacks in velocity during the first part, yet the entire space described must needs be less than 32 feet.

The space described by a falling body during any second of its fall equals half the sum of the initial and final velocities of the given second.

Entire space passed over.—The entire space described by a falling body = the sum of the spaces of the separate units of time. Thus, as has been seen, a body falling two seconds descends 16 ft. in the first second and $\frac{32 + 64 \text{ ft.}}{2} = 48$ ft. during the next. Consequently the entire space described from its starting point to the end of the second second = 16 ft. + 48 ft. = 64 ft. And from its starting point to the close of the third second 16 + 48 + 80 = 144 ft.

The entire space may be indicated by S to distinguish it from s, the space described during any portion of the entire time. Hence —

S	passed	over	during	1	sec.	$= (1.1) 16..$	$= 1^2.16$ ft.	= 16 ft.
S	"	"	"	2	"	$= (2.2) 16..$	$= 2^2.16$ ft.	= 64 ft.
S	"	"	"	3	"	$= (3.3) 16..$	$= 3^2.16$ ft.	= 144 ft.
S	"	"	"	4	"	$= (4.4) 16..$	$= 4^2.16$ ft.	= 256 ft.
S	"	"	"	5	"	$= (5.5) 16..$	$= 5^2.16$ ft.	= 400 ft.
S	"	"	"	6	"	$= (6.6) 16..$	$= 6^2.16$ ft.	= 576 ft.
S	"	"	"	10	"	$= (10.10) 16..$	$= 10^2.16$ ft.	= 1600 ft.
S	"	"	"	$4\frac{1}{2}$	"	$= (4\frac{1}{2}.4\frac{1}{2}) 16..$	$= 4\frac{1}{2}^2.16$ ft.	= 324 ft.
S	"	"	"	$\frac{1}{2}$	"	$= (\frac{1}{2}.\frac{1}{2}) 16..$	$= \frac{1}{2}^2.16$ ft.	= 4 ft.

The preceding table shows that the space passed over by a body falling under gravity = the square of the time into 16 ft. or $\frac{g}{2}$. Thus, the space, S, described by a body falling 10 sec. $= 10^2.\frac{g}{2} = \frac{1}{2}\,g.10^2 = 16.10^2 = 1600$ feet. (Fig. 8.)

The entire space described by freely falling bodies = the square of their time of fall into $\frac{1}{2}$ g.

(2) Formula: $S = \frac{1}{2}\,gt^2$.

Space described during any second.— Suppose that a body was 10 sec. in falling; what was the space passed over during the 7th second?

Solution: 16 ft. $7^2 = 784$ ft. $= S$ in 7 sec.
From this subtract 16 ft. $6^2 = 576$ ft. $= S$ in 6 "
Hence S in 7th sec. $= 208$ ft. = answer.

Additional Velocity. — If a body is projected vertically downward with a $v = 5$ feet a sec., and continues 5 secs. in falling under gravity, what will be the entire space described? The body obeys both forces and therefore describes $\frac{1}{2}\,g.5^2 = 400$ ft. by gravity, and $5.5 = 25$ ft. by the original velocity, in all 425 feet.

Projectiles.

Bodies projected vertically upward — Velocity. — Experience teaches that all bodies projected into

space return again to the earth. This proves that the end of their upward flight, their upward vel. = 0. The main cause of this retardation of velocity during their ascent is the earth's gravity; gravity also is the cause of their subsequent descent. The retardation during the ascent therefore must be equal to the acceleration during the descent. That is, as much motion as gravity takes from the body ascending, just so much motion gravity gives it in coming down. Suppose a stone was hurled vertically upward (Fig. 9) — in an unresisting medium and that four seconds elapsed before it reached the earth again. Evidently the stone will require as much time to rise as it does to fall; consequently it ascends in 2 seconds and descends in 2 seconds. But the velocity of a falling body at the end of 2 seconds = 64 ft.; hence the body in order to rise two seconds vertically must be projected vertically upward with a vel. = 64 ft. a second. The first second of its ascent corresponds in space to the last second of its descent; at the close of the first second its vel. will be 64 — 32 = 32 ft. a second and at the close of the next second its upward motion will be zero, in consequence of gravity. Since gravity continues to act, the body must now proceed downward; it acquires a vel. of 32 ft. at the end of the

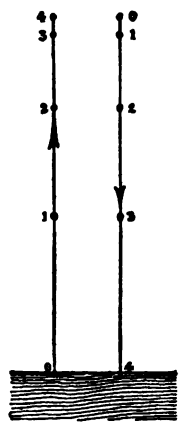


FIG. 9.—Vertical Projectiles. Vel. = 128 ft.

first second of its downward course, and a vel. of 64 ft. a second at the end of the next second, when it reaches the ground.

Example.— A body projected vertically upward was in the air 10 seconds. Required (1) the initial velocity; (2) the height to which it rose.

Solution (1): If it was 10 seconds in the air, it rose 5 seconds and descended during the next 5

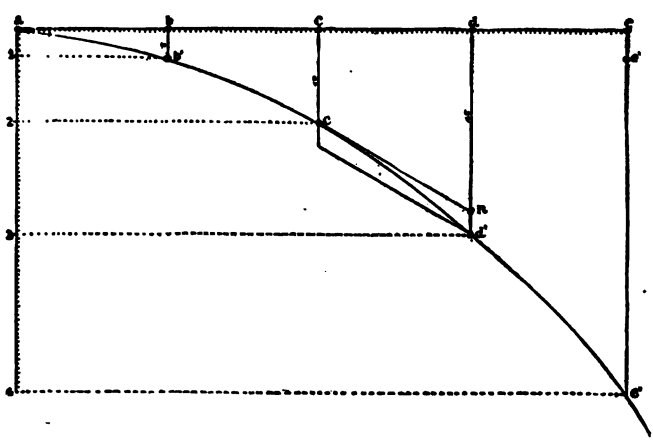


FIG. 10.—Horizontal Projectiles. Vel. = 128 ft.

seconds. Now, a body falling 5 seconds acquires a vel. = 5.32 = 160 ft., and this is the velocity with which it must have been projected.

(2) Since the body rose 5 seconds we have, according to formula $\frac{1}{2}gt^2$, $16.5^2 = 400$ ft., answer.

Parallelogram of Forces.— Let us imagine an iron ball falling from a point *a* (Fig. 11), under the influence of gravity; and that it would reach *c* in one second of time, then let us suppose that a magnet be placed at a great distance from the ball, attracting the ball in the horizontal direction, and representing a constant force like gravity, so as to attract the ball to *e* in one second. Then, owing to the joint action of both forces the ball will be found at the end of the first second of its fall at *d*, having passed from *a* to *d* in one second.

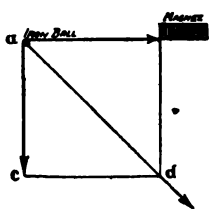


FIG. 11.
Parallelogram of Forces.

A body thrown out of a balloon traveling horizontally at the rate of fifty miles an hour will appear to an observer in the balloon to fall vertically downward, but to a person on the earth it will appear to fall obliquely. Why?

How will two observers, one stationary on the ground, the other standing in a railroad train in motion see the fall of an apple dropped from the hand of the latter?

The law for the parallelogram of forces is the same as the one given in Lesson VIII provided the term "force" be substituted for that of motion.

LESSON XIII.

CENTER OF MASS.

Center of Gravity.— Every force must have a point of application in order to act. Now gravity is a force; and its point of application resides in every material particle, for it pulls all such particles to the earth. Gravity exerts itself on every particle of the body in Fig. 12, whether the substance

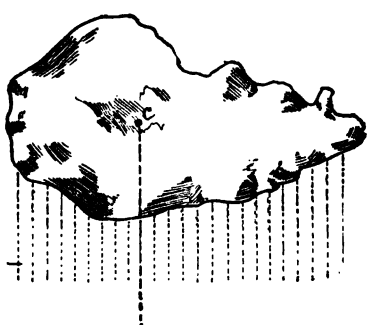


FIG. 12.
Center of Gravity and Line of Direction.

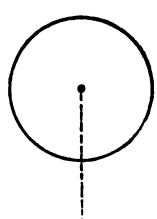


FIG. 13.
Center of Gravity, Center of Mass, and Line of Distance of a Homogeneous Sphere.

be sand or a piece of granite. From every particle composing the body a vertical line of pull by gravity may be imagined to extend. The pull amounts to the same for each equal particle; the pulls are sensibly parallel, and their direction is the same for all particles. The entire pull of g upon the body = the sum of all the individual pulls; this

sum constitutes the pull or push of the body, and when it is resisted by some obstacle, it results in what is called the "weight" of the body. The resultant of all the points of application of gravity is the point *c;* and the resultant of all the verticals is the vertical passing through *c*. That point is called the *center of gravity;* the vertical line passing through the center of gravity is called the *line of direction.*

Position of the Center of Gravity— 17TH EXPERIMENT.—**Suppose from any** of its corners, a triangular piece of sheet tin of uniform thickness and density. Then draw a line on it which has the same direction as the string. Next suspend it from another corner; again draw a line on the body, the line to be a combination of the direction of the string; then suspend it from the third corner, and draw a line on it as before. The three lines must all pass through the same point; and this point is the center of support or gravity of the piece of tin.

If now, by any of the three lines obtained, we cut the body in two, the two pieces will be found to be unequal in mass. The same will also be found if the body be cut into by any other straight line passing through the center of gravity. This shows that the center of gravity is not always the center of mass, although such is the case in a uniform sphere (Fig. 13) in a cube or a square surface.

In bodies having no great weight, the center of gravity is easily ascertained by suspending them, after the manner above described, from at least two different points. The two lines of direction so obtained contain each the center of gravity; therefore the point of intersection of the lines is the center of gravity. To prove this, suppose some other point to be the center of gravity, in this case one of the lines does not contain the center of gravity, which is contrary to actual conditions.

FIG. 14.
Center of Gravity of Triangle.

The above method of finding the center of gravity applies to irregularly shaped bodies. In bodies having regular forms and uniform density, it may be determined geometrically.

1. A triangle has its center of gravity at the intersection of the lines drawn from the vertices of any two angles to the middle of the opposite side. Such sides are called transversals. The distance of the center of gravity from any such middle is one-third the length of corresponding transversal (Fig. 14).

2. A circle at the intersection of any two diameters.

3. A parallelogram, at the intersection of its diagonals.

4. A sphere, at the center.

5. A cylinder, at the center of its axis.

6. The human body, in the abdomen.

7. A ring, or shallow sphere, outside the mass; but in such cases the center of gravity must be considered as rigidly connected with the body.

Property of the center of gravity.— An examination of Figs. 15 and 16 will convince us that if the center of gravity of a body be supported, the body will not move under the action of gravity; that is, it will not fall; and that, if it be not supported, the body will move under gravity or fall. Generally speaking, then, the center of gravity is that point in a body which, if supported, prevents the body from falling.

Equilibrium. — The center of gravity exerts a vertical downward pressure. If it is supported, the point of support exerts a vertical upward pressure. From article 39 we know that both pressures are equal in amount but opposite in direction. When general forces act at a point so as to neutralize each other, they are said to be in equilibrium. A body suspended by a string is in equilibrium with the tension of the string or with the point of suspension. So in a railway train with uniform motion, the force of the steam is in equilibrium with the resistance to be overcome; for if

the force of the steam be greater than the resistance, the motion of the train will be accelerated; if smaller, the motion of the train will be retarded.

A body is said to be in equilibrium when it is acted upon by forces that mutually neutralize each other. The preceding shows, that whenever the center of gravity — or the line of direction — of a body is supported, the body is in equilibrium with its support. Thus the center of gravity, *n*, or the line of direction *n o*, of the solid *a b c d* (Fig. 15), is supported; hence the solid *a b c d* is in equilibrium. But the center of gravity *n'*, — or the line of direction *n' o'*, of the solid *a e f d*, is not supported; hence *a e f d* is not in equilibrium.

Stable, Unstable and Neutral Equilibrium. — Upon the relative position of the center of gravity and the support of a body depends the three states of equilibrium just mentioned.

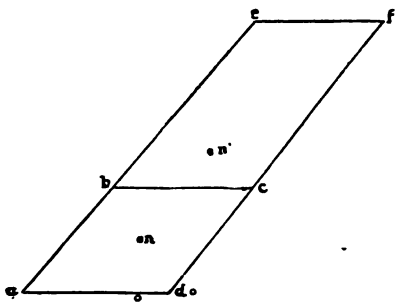


FIG. 15.

The center of gravity may be below the support, as in Figs. 16, 17, 18, 19, in this case the body is in stable equilibrium. The center of gravity may be above the support, as

in Figs. 20, 21, 22, in this case the body is in unstable equilibrium. Or it may be coincident with the support as in wheels and pulleys, in which case we have neutral equilibrium. These three states of equilibrium refer only to instances where the support is either a point or a line.

Stable Equilibrium (Figs. 16, 17, 18, 19).—All suspended bodies such as pendulums or a mari-

Stable Equilibrium.

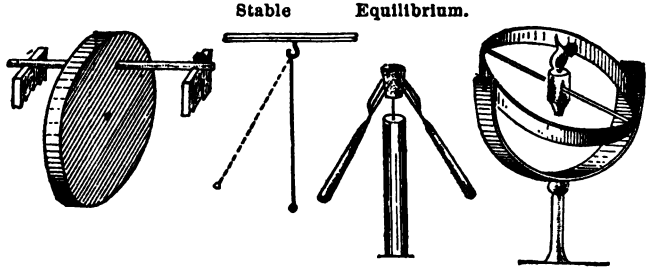


FIG. 16. Eccentric Wheel. FIG. 17. Pendulum. FIG. 18. Cork Supported on Needle-point. FIG. 19. Mariner's Lamp.

ner's compass, are in stable equilibrium. They are but little affected by slight disturbances, and easily resume their former position after the disturbing force ceases to act. It is characteristic of all suspended bodies: (1.) That their position is secure; (2) that their center of gravity rises whenever they are disturbed, provided the point of suspension remains fixed; (3) that after the disturbing force ceases, they return to their former position by their own weight; and (4) that in doing so, they produce

a series of oscillations which last until the center of gravity remains in the lowest position.

Unstable Equilibrium (Figs. 20, 21, 22) is only of momentary duration, because it may be destroyed by the slightest movement, such as a motion of the center of gravity, or of the support. In order that a body be in a state of unstable equilibrium the center of gravity must be vertically above the support.

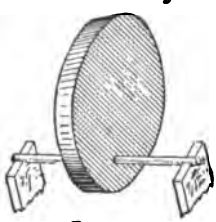


FIG. 20.

FIG. 21.

It is characteristic of all bodies in unstable equilibrium, that (1) their position is insecure, and (2) their center of gravity falls wherever they are disturbed.

FIG. 22.

Neutral Equilibrium. — This is the state of equilibrium of all bodies whose center of gravity coincides with the center of support. Although they remain stationary, they may be turned by the slightest pressure. It is characteristic of all bodies in neutral equilibrium that when they are turned, their center of gravity neither rises nor falls.

Stability of Bodies. — Most objects are supported in such a manner that

their center of gravity is above their support. If they were in a state of unstable equilibrium, that is, if their support consisted only in a point or line (Figs. 20, 21, 22) they would be totally

Neutral Equilibrium.

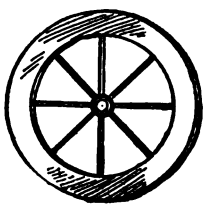


FIG. 23.
Carriage Wheel.

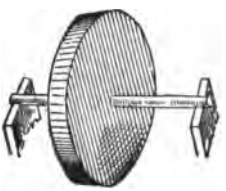


FIG. 24.
Grindstone.

insecure. The support of most objects, therefore, consists in the space included by the lines connecting at least three points not lying in the same straight line. This space is called the *base* of a body. A body falls when the line of direction passes outside of the base.

Applications. — Candlesticks and inkstands are made with broad bases. Stone walls are broader at the base than at the top. Tall monuments are made with their sides inclined and often have very large bases. The legs of chairs are inclined outward. A child's high chair has a very wide base. When we walk up hill we lean forward and in going down hill we incline backward, in order to keep the center of gravity over the base.

LESSON XIV.

THE PENDULUM.

18TH EXPERIMENT.— **The string by which a stone is suspended has a vertical direction. If the stone is drawn a little to one side, the direction of the string will be slanting. On letting the stone go now, it begins to move. Since all bodies are drawn to the earth, it will naturally approach the earth as near as possible. When nearest the earth, the string has the vertical direction. But the weight does not stop because its own inertia carries it onward; being held by the string it does not fall to the ground; it ascends, until gravity stops it. Gravity not only stops it, but also causes it to go down again; it descends with increasing velocity. Inertia causes it again to pass by the lowest point of its path; it ascends on the other side, stops an instant of time, and is then forced back again by gravity. Each *swinging in one direction* is called an *oscillation*. The oscillations grow shorter, and observation shows that, finally, they cease altogether.**

They are caused by the combined action of gravity and inertia. Were there no gravity, the pendulum would not oscillate at all.

Any heavy body suspended from a fixed point so as to swing to and fro, is called a Pendulum.

19TH EXPERIMENT.—**Let us take a pendulum** whose length, measured from the center of the weight, or *bob*, to the point of suspension, is 39 inches. If it be set swinging, and the oscillations counted, we find that each oscillation of a pendulum of that length is performed in a second of time.

20TH EXPERIMENT.— **Draw aside the weight** of pendulum suspended and at rest; then commence to count the oscillations by saying, at the instant of letting the weight go, "naught;" at the end of the first oscillation "one," at the end of the second oscillation "two," and so on for about 10 oscillations. Each number at the same time indicates seconds; the ten oscillations therefore have been performed in ten seconds. But as the oscillations were being counted, you will have perceived that they grew smaller and smaller, that is, the space, or *arc*, through which they passed, grew shorter and shorter, yet the time each oscillation required remained precisely the same, viz.: one second.

This circumstance in connection with pendulums is of great importance. But when the arc passed over by the weight is very large, the time for an oscillation is a little longer than a second.

The oscillations of one and the same pendulum take place in the same length of time.

A pendulum performing an oscillation in a second is called a "second pendulum." In the latitude of New York at the level of the sea the length of a second pendulum is about 39.1 inches.

21ST EXPERIMENT.— **Cut off three-fourths** of the string. The pendulum is now shorter than it was before; it has about one-fourth the former length. After it is set vibrating, count the number of its oscillations in ten seconds; the number will be found to be twenty. The reason of this is easily seen, if we suspend both pendulums, the shorter and longer, from the same horizontal rod. The former descends on a shorter incline than the latter, and, therefore, takes less time to descend.

The longer the pendulum, the longer the time required for it to make one oscillation; the shorter the pendulum, the shorter the time required for one oscillation. Or: *A short pendulum oscillates more rapidly than a long one.*

All bodies that can be made to oscillate around a fixed point or axis lying outside of their, or at least away from their, center of gravity, may be called pendulums. The simplest form of a pendulum is the mathematical pendulum. It consists of an imaginary

heavy point connected with a fixed point of suspension by means of an imaginary imponderable line. A mathematical pendulum has only imaginary existence; the nearest approach to it is a small ball of gold, or platinum, suspended by a fine thread. Ordinary pendulums are called physical pendulums. They are employed in demonstrating the laws of the pendulums, although these laws apply only to mathematical pendulums.

The Laws of the Pendulum are as follows: The time of vibration

I. Is independent of the mass or material of the pendulum.

II. Is independent of the amplitude, if small.

III. Is proportional to the square root of the length.

IV. Is inversely as the square root of g.

The pendulum, by means of the fourth law, affords the most accurate means of determining the value of g in different places.

LESSON XV.

MEASUREMENT OF FORCES.

a. By Weight.— When a body presses upon a spring, the spring is compressed; the amount of the compression can be expressed in weight. If the pressure of a body is vertically downward, then the amount of the pressure is the same as the weight of the body. If we wish to find the quantity of force necessary to break a thread, or the strain to which the thread can be exposed without breaking, we may attach small weights to it one after the other, until it breaks; the sum of all these weights represents the supporting capacity of the thread. The expansive force of the steam that moves the piston in the steam cylinder of a high pressure engine might be replaced by a corresponding weight pressing against the piston. The force of gravity is measured by weight. We conclude, therefore, that the forces of gravity, elasticity, cohesion and expansion can all be measured by weight.

b. By Momentum.— The most general effect of force, however, is motion. It is often important to measure the force that gives a body a certain velocity. Force may be measured by the amount

of velocity it can produce in a unit of time. Force may also be measured by the amount of velocity or momentum, which it can stop in a unit of time; for, in order to stop momentum, a certain amount of momentum in the opposite direction is required; now this amount is the same as the amount required to produce the momentum of a body.

I. Suppose an iron ball weighing fifty pounds to move from a state of rest through the space of one yard in a unit of time. Next imagine that another iron ball of the same weight moves with the same velocity. Then the force acting on this ball will be of the same magnitude as the force acting on the other ball.

II. Now, if we conceive both balls to be united into one body, and the two forces to act on this united body, then this 100 lb. ball will still move with the same velocity. Twice the force is evidently required to generate the same velocity in twice the mass; and we conclude that in unequal masses moving with equal velocities, the moving force is proportionate to the masses, or, in other words, to generate the same velocity in the same time, the moving force must vary as the mass.

III. If two equal masses (of the same substance) move with unequal velocities, it is self-evident that the mass with greater velocity is impressed by the

greater force; that is, the velocities are proportionate to the forces.

IV. If an iron bar weighing 100 lbs., and another weighing 1 lb. are each set in motion by an equal force, then the velocity generated in the heavier ball will be less than the velocity generated in the lighter ball; that is, the velocities generated in the same time will be inversely as the masses. For since the 100 lbs. receive the same force as the one pound, each of the 100 pounds receives only one-hundredth portion of the force impressed upon the pound ball, and it can have only one-hundredth the velocity. The velocity of the one lb. ball therefore is 100, and that of the 100 lb. ball is one. We naturally conclude that whenever unequal masses are acted upon by equal forces, their velocities will be inversely proportionate to the masses; or that the velocity generated in the same time by the same force is inversely proportionate to the mass.

Familiar Facts.— The effect of a leaden bullet fired from a rifle is greater than that produced by the same bullet thrown with the hand. An ax swung quickly has greater effect than one swung slowly; a wheel rotating by steam power is more effective than one turned by hand.

In order that the ideas of mass and velocity may be more fully impressed upon the student by facts,

he should turn a grind-stone, or a fly wheel, and then try to stop its motion. Besides, he should frequently observe the motion of heavy masses.

Work.— If a body weighing a pound is to be raised vertically ten feet, its downward pressure must be overcome from below upward through the center space of ten feet. If a railway train is drawn thirty miles, the resistance caused by the friction on the rails must be overcome through the entire length of thirty miles. If a log is to be sawn, the saw must overcome the resistance of the cohesion of the wood at every point of contact. In each of these cases, the greater the resistance to be overcome, and the greater the space to be passed over, the greater is the amount of work to be performed. Of two laborers engaged in shoveling earth from a lower level to a higher, he that when the day's labor is over, has thrown up twice as much earth as the other, has performed twice as much work, and consequently earned twice as much pay as the other. For work depends upon resistance overcome.

Again, if of two equal quantities of earth, one is thrown up six feet high while the other has been thrown up only one foot high in the same time, the former implies double the amount of work done. It is clear then (1) that the resistance being the same, work is proportionate to the space described;

and (2) the space described being the same, work is proportionate to the resistance overcome.

Definition of Work. — In raising weights, in drawing loads, in sawing wood or driving nails, the changes are produced by the application of some force. The log, for instance, is sawn in two by the force that acts upon the saw. The saw, therefore, represents the force that overcomes the cohesion of the wood. To divide the log, either the saw or the log must be in motion, for if both remain at rest the log will not be sawn through. In other words, no work is done unless the force of pressure between the wood and the saw is in motion. A force at rest can overcome resistance only at one point, that is at the point of contact. Now, work means the overcoming of resistance not at one point alone, but at a great many points; hence a force at rest is incapable of performing work; that is a force in order to perform work must move through space.

In a physical sense, therefore, *work is the product of a force into the space described by the force.* Symbol: *Ws.*

Measure of Work. — Work is measured by a unit of its own kind, which we may select as we choose. The commonly accepted unit is the foot-pound; that is, the work done when one pound is raised one foot vertically high, whatever may be the

time required. According to the metric system, the unit of work is the meter kilogram, also called kilogrammeter. This term denotes the work done when one kilogram is raised 1 meter vertically in any length of time. A unit of work, then, is denoted either by a foot-pound or a meter kilogram.

A hundredweight falling from a height of 5 feet represents a work of $100 \times 5 = 500$ ft.-lbs.; that is, by means of suitable machinery, the weight will raise 1 pound 500 ft. high, if there is no friction. — If a person turns a crank the resistance of which is 1 kil., and if his hand passes through a space of 10 meters, his work is 10 met. — Two workmen in a hand-car which requires a force of 10 lbs. to continue in motion, if they move it 100 feet, their work amounts to $10 \times 100 = 1000$ ft.-lbs. (The force of 10 lbs. is here employed to overcome the friction between the wheels and the track.)

The term "work" is used to denote any change in the state, condition or position of a body. The work performed by a machine consists in pulling or pushing some point, or points, connected with a resistance; as when a steam engine lifts a hammer the weight of which may be assumed to center in a single point, the center of gravity. Or when corn is ground by horse-power, in which case particles are rent asunder; or when a blacksmith hammers an iron bar, in which case a change is made in the position of the particles of iron.

From the preceding article it might appear that no work is performed when the center of gravity of a body moves in a horizontal direction, because in this case no weight is lifted against the resistance of gravity. For example, is there work performed when a railway train moves on a horizontal track? The answer is: There is work done, but it is not work done against gravity, for after the inertia of the train is overcome, its horizontal motion continues of itself (First Law of Motion); but in order that the train may move on work must be done against the friction between the wheels and the rails. The work done by the train is equal to the amount of the friction into the space passed over. Let the weight of a train be 500,000 lbs., and let its motion = 500 ft. on a horizontal track, and the rolling friction against the rails = $\frac{1}{250}$ of the train. Then we have $\frac{500000}{250}$ = 2,000 pounds, into 500 feet of space = 1,000,000 ft.-lbs. of work; that is, 2,000 lbs. of pull are required to keep the train in motion. The entire work of 1,000,000 ft.-lbs. consists in work done against friction, not against gravity, but it is measured by a common standard of measuring work, viz.: the foot-pound. If the train traveled the same distance with "brakes down," the amount of work would be far greater. Suppose that the brakes be applied to all the wheels; the sliding friction thus produced would be one-tenth of the weight of the train; and the entire work done = $\frac{500000}{10} \times 500$ = 2,500,000 ft.-lbs.

LESSON XVI.

ENERGY.

The energy of a body is its power of doing work. We may drive a nail into a board by placing a weight upon the nail sufficient to sink it into the board. The gravity of the weight overcomes resistance as it moves the nail, which means that it performs work. The amount of work performed is equal to the force multiplied into the space through which the nail passes. But it is more convenient to drive a nail by means of the blows of a hammer: in this case the work done is equal to the mass of the hammer *into* the velocity of the blow. — In drilling a hole into a board by means of an auger we give it sufficient force to wind its way through the wood; but a bullet fired from a rifle can do the same. The auger does its work by virtue of the constant power acting upon it gradually; no power accumulates in the auger. But the bullet does its work in obedience to an impulsive force imparted to it, not gradually but in an instant, which remained in it during its flight, and was finally spent in working its way through the board. — The hammer of a pile driver is raised to a certain height and then allowed to drop; it falls upon a pile to which it imparts its own motion.

Each of the foregoing examples illustrates the case of a body endowed with the power of doing work, that is, with energy. Instances of bodies possessing energy are very numerous.

Kinetic and Potential Energy. — The energy that bodies possess by virtue of being in motion, is called *Kinetic energy.* In the previous examples the hammer and the rifle-bullet possess Kinetic energy, because one of the agencies through which they performed their work was motion.

Now suppose that the hammer of the pile-driver alluded to in the preceding article, after being raised to a certain height, had been kept suspended there. It would then have constantly tended to fall; its power for doing work would merely have been suspended for the time, and we can speak of its energy as being stored up in the hammer during the time of suspension ready to be expended whenever the hammer should be dropped. The same holds true of a stone that was thrown on the top of a house. Its Kinetic energy carried it to the roof; and from the instant it lodged on the roof, its velocity was *zero.* Let us suppose that the stone remained on the roof; then during the entire time of its remaining there it had a tendency to fall. This tendency is an example of *Potential* energy; so is the tendency to fall of the uplifted hammer of a pile-driver. *Potential energy* is the energy bodies

possess by virtue of their being at rest. — A drawn cross-bow, or a coiled watch-spring also illustrates potential energy.

Circular Motion. —Let a heavy object be suspended by a string and then make it revolve around the point of suspension of the string. If gravity, the resistance of the air, and the friction at the point of suspension were out of the way, the object would revolve permanently. Circular motion arises whenever a body receives an impulse and is then urged by a continuous force toward a point not in the direction of that impulse. Circular motion is motion around a fixed point. This point is the center of motion; the force which urges the body towards the center is, in the present case, the cohesion of the string; its general name is Centripetal force. The force with which the body tends to fly away from the center is called Centrifugal force; in the above experiment Centrifugal force stretches the string during the revolution of the object.

Familiar Facts.— Grindstones and flywheels are good illustrations of circular motion. This cohesion represents the centripetal force. Sometimes pieces fly off, causing great damage; this takes place when the centrifugal force of the parts at the circumference far exceeds the centrifugal force or cohesion. Gravitation causes the earth and the remaining

planets to revolve around the sun; hence gravitation, like cohesion, may appear as centrifugal force.

Effects of Centrifugal force on Rotating Masses. The effect of centrifugal force produced by the rotation of the earth is very small. At the equator, where centrifugal force acts at a right angle to the direction of gravity, it diminishes the intensity of gravity by $\frac{1}{288}$; that is, at the equator the weight of all bodies is $\frac{1}{288}$ less than at the equator of an earth at rest. Toward either pole, centrifugal force diminishes; and at the poles it is 0.

22ND EXPERIMENT.—**If two circular** hoops of tin or brass be provided with an axis so that they can be whirled around easily, rapid rotation on the whirling table, or twirling the axis between the fingers will cause them to assume the flattened shape. (Fig. 25.)

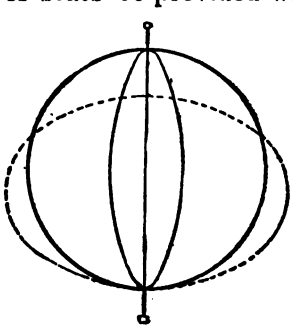


FIG. 25.
Centrifugal Force.

23RD EXPERIMENT.—**If a glass flask** containing water and mercury, be whirled by means of a string, the mercury having greater specific weight, will obtain the greater centrifugal force, and therefore rise, forming the equator, with the water on both sides. (Fig. 26.)

Centrifugal force causes the equatorial diameter of the earth to be nearly 26 miles longer than the polar diameter.

The general effect of centrifugal force upon rotating masses is to flatten them at the poles, to increase their equatorial dimensions, and to produce a tendency in their particles to fly from the center, in the direction of a tangent to the circle, that is, at right angles to the radius.

FIG. 26. Centrifugal Force.

The earth and the moon are inseparably united by gravitation; the centrifugal force of the moon at every instant tends to pull the earth towards it. Similarly the hand whirling a stone at the end of a string experiences a pull toward the stone. The equilibrium between the moon and the earth is preserved by their simultaneous revolution around a common center of mass, which, as the moon's mass, is but $\frac{1}{88}$ of that of our globe, lies far within the interior of the earth.

Familiar Facts. — Water, or mud, flying from the wheels of a carriage in rapid motion. — A glass filled with water suspended by a cord fastened around the rim, may be whirled vertically without loss of water. — Every revolving object receives the influence of centrifugal force as a pressure which tends

to throw it outside of its course. Hence a circus-rider passing rapidly round the ring, inclines toward the center in order that the resultant of his weight and centrifugal force shall still fall between his feet. — A railway car turning on a curve is under the influence of centrifugal force.

Applications of Centrifugal Force. — 1, the governor, to control the speed in engines; 2, the fan in the "ventilator" or "blower," to ventilate mines and to feed blast furnaces; 3, the centrifugal pump; 4, the centrifugal drying machine, where centrifugal force expels the water in clothes placed in a rotating drum with perforated sides; 5, a contrivance similar to the preceding, used in sugar refineries to separate liquid sugar from solid.

LESSON XVII.

REVIEW.

40. Universal gravitation is known to account for: 1, the revolutions of the heavenly bodies; 2, the perturbations of the planetary orbits, and 3, the tides.

41. *All bodies seem to be attracted* to the earth. The force which moves them to the earth is called the Force of Gravity.

42. *All bodies fall if unsupported;* if *supported*, they press upon their support; if *suspended*, they pull in the direction in which they would fall if left free to do so.

43. *The direction in which a body falls*, if it is moved by gravity alone, is *vertical*.

44. *The pressure of bodies* upon their support, or their pull when suspended, is called Weight.

45. *A pound is a weight*, indicating a certain amount of downward pressure or pull taken as a standard.

46. In our latitude, and in the level of the ocean, a body that falls freely from a state of rest, is pulled down by gravity 32.1816 feet every

second of its fall. This is ordinarily expressed by $g = 32$ feet.

47. The velocity acquired by freely falling bodies = the product of their time of fall into g.

48. The space described by a freely falling body during any second of its fall = half the sum of the initial and final velocities of the given second.

49. The entire space described by a freely falling body = the sum of the spaces of the separated units of time; or, the square of their time of fall into $\frac{1}{2}\, g$.

50. A body projected into space returns again to the earth. Its starting velocity = its velocity with which it returns to the point from which it started.

51. The law of the parallelogram of forces is the same as the one given for the parallelogram of motion.

52. The center of gravity of a body is the resultant of all the points of application of gravity.

53. The vertical line passing through the center of gravity is called the line of direction.

54. As long as the center of gravity of a body is supported, the body will not move under gravity; that is, it will not fall.

55. A body is in equilibrium when it is acted upon by forces that mutually neutralize each other.

56. Stable, unstable and neutral equilibrium depend upon the relative position of the center of gravity and the support of a body. When the center of gravity is below the support the body is in stable equilibrium; when it is above the support, the body is in unstable equilibrium; if it is coincident with the support, as in wheels, the body is in neutral equilibrium.

57. A body falls when the line of direction passes outside of the base.

58. Any heavy body suspended from a fixed point so as to swing to and fro, is called a pendulum.

59. The oscillations of the same pendulum will take place in the same length of time, unless these vibrations pass through large spaces or arcs.

60. A short pendulum oscillates more quickly — makes a greater number of oscillations in the same length of time — than a longer one.

61. A body that can be made to oscillate around a fixed point or axis lying outside of it, or at least away from its center of gravity, may be called a pendulum of gravity, elasticity, cohesion and expansion.

62. The forces may be measured by weight.

63. Force may also be measured by the amount of velocity it can produce or stop in a unit of time.

64. Work is generally measured by the "foot-pound," which means the work done when one pound is raised one foot vertically high.

65. The term "work" denotes any change in the state, condition, or position of a body.

66. The energy of a body is its power of doing work.

67. The energy that bodies possess by virtue of being in motion is called Kinetic energy.

68. The energy that bodies possess by virtue of their being at rest is called Potential energy.

69. Circular motion arises whenever a body receives an impulse, and is then urged by a continuous force toward a point used in the direction of that impulse.

70. Circular motion is motion round a fixed point, which point is the center of motion.

71. The force which urges the body toward the center is called Centripetal force.

72. The force with which the body tends to fly away from the center is called Centrifugal force.

73. The general effect of centrifugal force upon rotating masses is to flatten them at the poles; to increase their equatorial dimension, and to produce a tendency in their particles to fly from the center, in the direction of a tangent to the circle, at a right angle to the radius.

PART III. — MACHINES.

LESSON XVIII.

THE PULLEY — WEIGHT — POWER.

Work, or mechanical labor, is measured by multiplying the force applied into its space described. Suppose a person wishes to raise a beam weighing 150 pounds, 16 feet high; he finds he cannot do it without the aid of some simple machine, such as the pulley.

The Pulley consists of a disc freely revolving about an axis, the ends of which are fixed into a frame called the block. The circumference of a pulley is generally grooved so as to allow a cord or chain to pass around it. Pulleys are *fixed* or *movable*, according as the block is fixed (Figs. 27 and 28A) or movable (Fig. 28B). The cord passing over a pulley is in a state of equilibrium only when its tension is the same on both sides. Thus in Fig. 27, cords *a* and *b* are in a state of equilibrium, because each cord supports the same weight, viz., 150 pounds; therefore the tension to which *a* is exposed is the same as that of *b*. In order to raise the weight *S*, a small weight must be added to *V*, just sufficient to overcome the friction at the axle and the stiffness in the cord. Hence, the power applied to raise a weight, with the aid of a single fixed pulley, must be a little in excess of the weight.

In other words: *By means of a fixed pulley alone, no mechanical advantage is gained.* It is generally used merely for changing the direction of a force or motion.

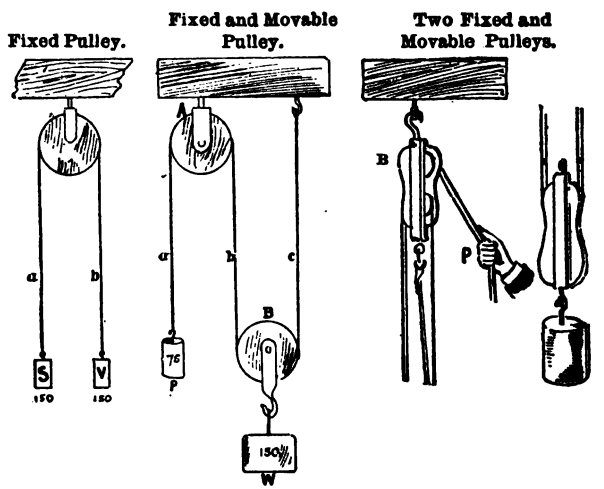


FIG. 27. FIG. 28. FIG. 29.

In raising a load the resistance to be overcome is the gravity of the earth. In splitting a log the resistance to be overcome is the cohesion of the particles of wood. In dragging a load along the ground, the resistance to be overcome is the friction between the log and the surface of the ground. All such resistances are comprised in Mechanics under the term "Weight." In general: *The external resistance to be overcome by a Machine is called the Weight.*

By the "Power" is meant the force or pressure applied to a machine for the purpose of moving the Weight.

A "Machine" is an arrangement of moving parts by means of which an available pressure, force, or power can be changed into some form of motion. There are six so-called simple machines, viz.: (1) The Pulley; (2) The Lever; (3) The Wheel and Axle; (4) The Inclined Plane; (5) The Wedge; (6) The Screw.

Let us imagine that a beam weighing 150 pounds be attached to the movable pulley *B*, Fig. 28. A rope passes round both pulleys; at its free end hangs the Power, *P*. Part *b* of rope *a b c* is exposed to a pull, or tension, of 75 lbs; and part *c* also to a tension of 75 lbs., therefore part *a* to be in equilibrium with part *b* requires a downward force of 75 lbs., which is attached to its free end. And as friction and other resistances are here neglected, it is clear that a single grain added to *P* should overbalance the pulley, that is, cause the 75 lbs. (which are now the Power) to descend and *W* to rise. But while *W* rises 1 foot, part *c* of the rope *a b c* is shortened 1 foot; and part *b* is also shortened 1 foot; hence the Power must descend 2 feet.

The preceding shows that a given amount of force may, by means of a movable pulley, be in

equilibrium with twice the amount of force attached to the movable pulley; or, what is the same, that a given Power, P, may set in motion a weight $= 2P$. But in order that this may be done the space passed over by the Power must be twice as great as the space passed over by the Weight. Hence what is gained in Power is lost in Space.

According to the equation of work, we have — supposing P to be unknown: —

$P\ 2 = 150.1$; or $2\ P = 150$, whence $P = 75$ pounds, the power required to raise the beam. In Fig. 29, p. 89, one string passes round four pulleys, two in each block. As in every part of the string the tension is the same, and there being four strings, all of which support W, it is clear that $W = 4\ P$; or that P, the force required to prevent W from descending, $= \frac{W}{4}$. With two movable pulleys, therefore, the mechanical advantage gained is four; that is, one pound of power will be sufficient to raise *four* pounds of weight (neglecting all internal resistances, and supposing the strings or ropes to be parallel). But if W rises one inch, P sinks four inches; this shows again that what we gain in power is lost in space.

The Mechanical Advantage of a Machine is the ratio of the Weight to the Power. Thus, if a Weight of four lbs. is raised by a Power of 1 lb.,

the mechanical advantage $= \frac{4}{1} = \frac{W}{P}$. This value $\frac{W}{P}$ is the measure of the efficiency or *working power* of a Machine. In the system of pulleys represented in Fig. 30 we have three strings supporting W; hence $W = 3P$, and $P = \frac{W}{3}$. The advantage gained by this combination of pulleys $= \frac{W}{P} = 3$; but for every inch that W rises, P must descend 3 inches.

Advantage gained by the Pulley.— It was shown that no mechanical advantage is gained by means of a fixed pulley alone; that an advantage of 2 is gained by a combination of one fixed and one movable pulley. But a system of two fixed and one movable pulleys gives us an advantage of 3, inasmuch as the fixed end of the string, instead of being fastened to the upper block, is fastened to the lower, thus giving an additional string to support the Weight (Fig. 30).

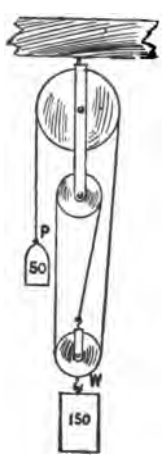


FIG. 30.
Two Fixed and One Movable Pulley.

In all systems of pulleys in which the same string passes round all the pulleys, the advantage gained equals the number of strings at the lower block.

LESSON XIX.

THE LEVER.

24TH EXPERIMENT.— **Balance a rod on the edge of a slate supported between two heavy books. The rod is in a state of equilibrium, because on each side of the point of support there is an equal amount of matter. Now, place the rod in such a manner that on one side of the support it shall be twice as long as on the other. The longer arm will descend, because it contains more matter. Let us repeat this slowly. Observe, that in lifting the end of the long arm with the hand, it moves through a greater space than is passed through by the end of the short arm. The lengths of the two arms of the lever are in ratio of 1 to 2; and the space passed through by the end of the long arm is twice as great as that passed through by the other. Notice, also, that the ends describe these unequal spaces in the same length of time; therefore,** *the end of the long arm of a lever has greater velocity than the end of the short arm.*

The general principle of the lever may be expressed by the following equation of work:—

P into its distance from the $F = W$ into its distance from F. The advantage gained by the lever therefore, is $\frac{W}{P}$.

Any rigid rod made to turn about a fixed point or fulcrum, is a lever.

Three Kinds of Levers.— There are three kinds of levers, distinguished from each other by the position of the fulcrum with respect to the power and the weight (Fig. 31). Where F is between P and W, the lever is of the first kind; the levers mentioned in the preceding article are of this kind. Where W is in the middle, the lever is of the second kind; and where the P is in the middle, the lever is of the third kind.

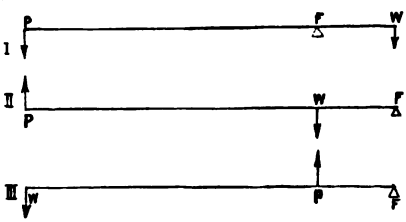


FIG. 31.
The Three Kinds of Levers.

Familiar instances of levers of the first kind are the crowbar and the balance; of the second kind, a nut-cracker, an oar propelling a row-boat, and a wheelbarrow; of the third kind the fore-arm when lifting a weight by turning about the elbow.

LESSON XX.

WHEEL AND AXLE.

The wheel and axle consists of a wheel and a cylinder or axle, which turn together round the same axis (Fig. 32). The weight is attached to the end of a cord winding round the axle; the power

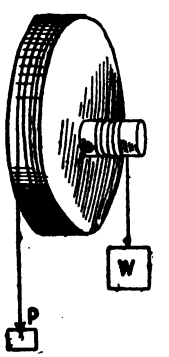


FIG. 32.
Wheel and Axle.

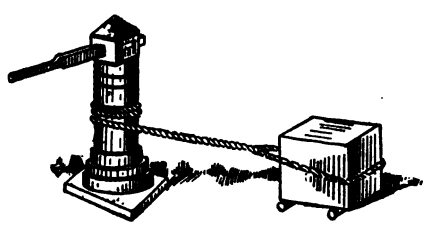


FIG. 33.
Capstan.

is applied at the circumference of the wheel, either as in Fig. 32, by means of a cord, or as in Fig. 33, by the hand. The cord supporting the weight is wound round the axle in the contrary direction; hence when W rises, P descends. Let the circumference of the axle in Fig. 32 be 1 inch, and that of the wheel 20 inches. Then in one revolution of the common axis W rises or falls 1 inch while P passes through

20 inches; the advantage gained, therefore, is $\frac{P}{W} = \frac{20}{1} = 20$. Hence a force of 1 pound at P will balance a force of 20 pounds at W (neglecting the slight surplus weight or force, required to produce motion and overcome friction), 1 pound of P applied will be able to raise a weight of 20 pounds.

The general principle of the wheel and axle may be expressed by the following equation of work (denoting the circumference of the wheel by Π, and the circumference of the axle by π): —

$P\Pi = W\pi$; or, by the proportion $P : W :: \pi : \Pi$.

Circumference being to each other as their respective diameters or radii, the above equation and proportion may, for many reasons, be stated thus: $PR = Wr$, and $P : W :: r : R$, in which $R =$ the radius of the wheel, and r the radius of the axle.

The advantage gained by the wheel and axle $= \frac{W}{P}$ or $\frac{R}{r} = \frac{\text{the radius of the wheel}}{\text{the radius of the axle.}}$

The Capstan (Fig. 33) is a modification of the wheel and axle. Its axle is vertical, with a long pole inserted to the center. This pole $= R$; hence the equation of work is the same as above.

LESSON XXI.

CLOCKS.

A clock is a contrivance that measures time by means of a combination of wheels, moved either by a falling weight or by an expanding spring, and regulated by a pendulum.

Where a clock derives its motion from a falling weight, the weight is attached to a string or chain; the downward pull of the weight is communicated to the string; the string turns the horizontal axle round which it is wound, and, with this axle, the entire train of wheels in the clock. The axle is fastened inside of a toothed wheel, which must

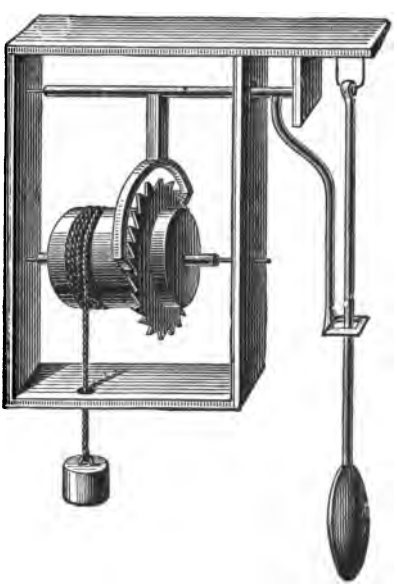


FIG. 34.

therefore turn with the axle. The pendulum rod is fastened to a horizontal rod, to which the pendulum rod communicates its motion. To this horizontal rod is fastened the *escapement*, *A A*, (Fig. 35) which terminates in two projections, or *pallets*, working alternately with the teeth of the wheel. Now this wheel together with its axle are acted upon by the falling weight, and therefore tend to move continuously; but they are prevented from moving continuously by the escapement. And the weight, the string of which winds round that axle, is consequently prevented from falling freely. For if it were permitted to fall freely, it would move downward very rapidly; its rapid motion would be communicated to the axle and toothed wheel, and the clock would "run down" within a few seconds. The purpose of a

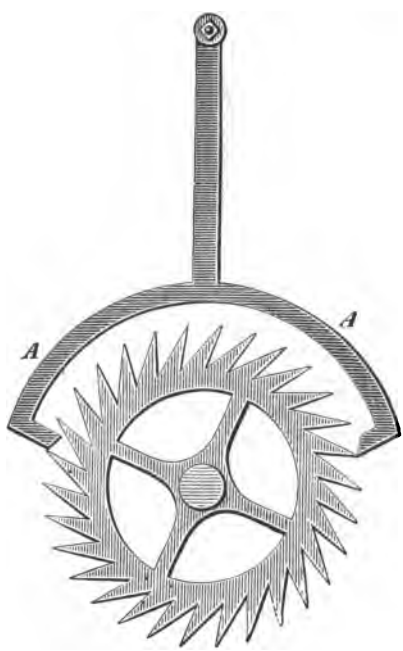


FIG. 35.

clock, however, is to continue in uniform motion for days or weeks.

With the pendulum at rest, the wheel is held at rest by both pallets; the weight, being prevented from descending, is also at rest; and the entire clock work is at rest. Now let the pendulum be set swinging, in which case one of the pallets is raised; the wheel has *escaped* from the confinement in which it was held by the pallet; the axle has revolved a short length of space during the quick escape or turn of the wheel; the string has been lengthened and the weight allowed to drop the same short length of space. All that movement begins with the escape of the wheel from one of the pallets, and ends when the wheel is blocked again by the other pallet; in other words, that movement takes place during one oscillation of the pendulum. At the next oscillation the other pallet is raised, allowing the wheel, axle, string and weight again to move a short space — the space being the same length as before — until the wheel is stopped again by the opposite pallet coming in contact with it. We see, then, that the oscillations of the pendulum alternately permit and arrest the descent of the weight. The pendulum is truly said to *regulate* the clock; for it causes the wheel to move in equal portions of time, since, as we have seen, the pendulum oscillates in equal portions of time; and if the wheel turns in equal portions of time, the entire clock-work

(which receives its motion from the wheel) must move in equal portions of time.

In watches the *balance wheel* performs the work of a pendulum.

In the ordinary *eight-day clock* (Fig. 36) the great wheel turns round once in 12 hours; it may have 96 teeth. The little wheel, to the left, which works into it, is called a "pinion." This pinion may have 8 teeth; if it has, then it will turn twelve times while the great wheel turns once. As the great wheel turns once in 12 hours, that pinion of the center wheel must turn once in an hour; hence it is made to carry the *minute hand*. The pinions of the second wheel and that of the scape-wheel have 8 teeth each, and the center and second wheels have 64 and 60 teeth respectively; hence the pinion of the second wheel turns $\frac{64}{8} = 8$ times in

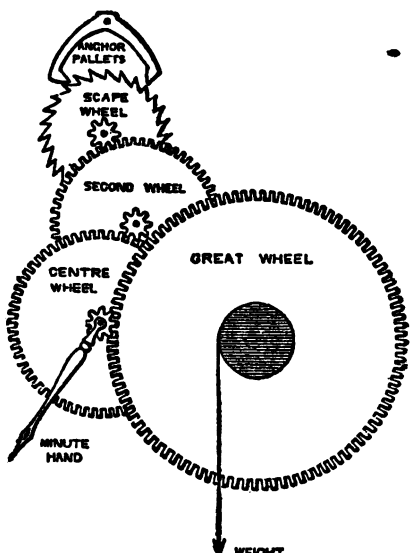


FIG. 36.—EIGHT-DAY CLOCK.
(*Taken from Goodeve's Elements of Mechanics.*)

an hour, that is, it revolves 8 times while the center wheel turns once; consequently it turns once in $7\frac{1}{2}$ minutes. And the second wheel also turns once in $7\frac{1}{2}$ minutes. The pinion of the scape-wheel turns $\frac{60}{8} = 7\frac{1}{2}$ times (while the second wheel turns once); that is, it turns once in $\frac{7\frac{1}{2}}{7\frac{1}{2}} = 1$ minute; and the scape-wheel turns once in a minute. If the pendulum swings 60 times a minute, or once in a second, the scape-wheel will have 30 teeth, and will, as said before, turn once in a minute.

The *hour hand* of a clock moves $\frac{1}{12}$ as fast as the minute hand. Its motion is derived from the center wheel by means of a train of wheels, the last of which moves $\frac{1}{12}$ as fast as the center wheel. In most clocks the force which produces the motion of the entire clock-work, is produced by the expansion of a compressed spring instead of the fall of the weight.

It may be asked why the pendulum in a clock is not brought to rest by gravity and other impediments.

The answer is, that whatever the pendulum in a clock loses by friction and the resistance of the air, it receives again from the contact with the teeth of the wheel.

LESSON XXII.

THE INCLINED PLANE.

25TH EXPERIMENT. — **A ball lying on a book** upon a table will not fall as long as the book lies in a horizontal position. But let the book be raised on one side and the ball rolls down. It rolls down the faster the higher the book is tilted. The ball presses with its whole weight upon the book, but when the book is raised a little on one side the ball presses less, and begins to fall. The higher we raise the book the less will the ball press upon it, and the more rapidly will it descend. The surface of the book when raised on one side, is an inclined plane.

Familiar Facts. — A wagon descending a steep hill need not be drawn by the horses; it is checked rather, in order to prevent it from rolling down too rapidly. When ascending a hill, the horses have a more difficult task than on a level road.

It is tiresome for us to ascend *steep stairs*. In loading wagons the *skid* is used. It saves much labor, if it is not placed too steep. If the wagon is very high, the skid must be quite long. The steeper an inclined plane, the greater the velocity of a *body*

descending on it; and the greater the force required to ascend it.

A rigid plane, inclined at any angle to the horizon, is an Inclined Plane. All roads that are not horizontal may be considered inclined planes. Fig. 37 represents an Inclined Plane; *A B* is the length of the incline, *B C* the base, *A C* the height, and angle *A B C* the angle of inclination of the plane.

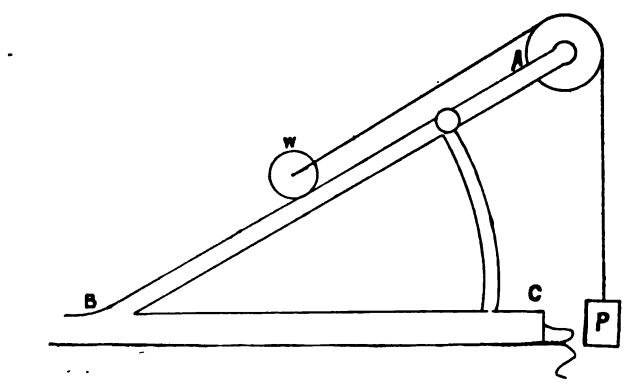


FIG. 37.
Inclined Plane.

Advantage gained by Inclined Plane — I. When the force applied acts parallel to the Plane.— Let a body the weight of which is *W* (Fig. 37) be moved from *B* to *A* by the action of a force *P*. The work done by *P* is *P.B A*; and the work of *W* is work done against gravity, that is, *W* is to be raised, against gravity, through space *C A;* hence the

work done by W is $W.A\ C$; and the equation of work is $P.A\ B = W.A\ C$, whence

$$\frac{W}{P} = \frac{A\ B}{A\ C}, \text{ or } \frac{\text{length}}{\text{height}}.$$

This means that the advantage gained by an inclined plane (when the force applied acts parallel to the plane) is found by dividing the *length* of the incline by its vertical *height*. If slope $A\ B = 24$ ft. and height $A\ C = 4$ ft., then a force of 1 lb. at P will balance a force of $\frac{24}{4} = 6$ lbs. at W, because the advantage gained $= \frac{24}{4} = 6$

But it will be observed that for every foot through which the weight is raised the power applied is obliged to pass through 6 ft.

When the force applied acts parallel to the Base. In this case the force is horizontal, and generally a pushing force acting in the direction $B\ C$, that is, parallel to the base. The equation of work in this case is $P.B\ C = W.A\ C$, whence

$$\frac{W}{P} = \frac{B\ C}{A\ C}, \text{ or } \frac{\text{base}}{\text{height}}.$$

The force that sets a ball on an inclined plane in motion, is the force of gravity. The reason why it rolls down along the incline, is that it is not fully

supported when on the incline; whereas on a horizontal plane it is fully supported. To make the ball stay on the incline it must be kept in place either by pushing it from below, or by pulling it from above.

Application — 1. *To overcome weight:* A road winding up a hill. A skid; an obliquely-placed plank; wedges and axes.

2. *To exert strong pressure:* Wedges used in oil-works, sugar-mills, etc., to press out the juice.

3. *To overcome cohesion:* Our knives, axes, hatchets, scissors, needles, nails, swords, bayonets, saws, files, chisels, planes, plows.

4. *The Screw*, which consists of a cylinder with a projecting thread or inclined plane wound round its surface. It is used in raising buildings temporarily from their foundations, as well as for other purposes where great force is necessary. The common letter copying press is another example of the application of the screw.

LESSON XXIII.

LAW OF MACHINES — PERPETUAL MOTION.

The great law of machines may now be stated: *What is gained in power is lost in space or time.* This law is also called the law of *Virtual Velocities;* the word *virtual* is used to indicate that the motion referred to may be *supposed* to take place, but need not actually take place.

Perpetual Motion.— If a machine, once set in motion, would move on without the help of external force, and would continue moving without losing any of its momentum, until its material were worn out, such motion would be Perpetual Motion. If a clock, for example, once wound up should go forever without being wound up again; if the parts of a steam engine, once in motion, should continue moving without the need of fuel of any kind, these would be instances of perpetual motion. But it is impossible that mechanical contrivances can ever be realized that move on forever without any fresh supply of power, because all machines in motion meet with resistance such as friction or percussion, to overcome which a quantity of energy is constantly spent. This energy must be replaced, else the moving parts of the machine will come to rest.

Besides that quantity, another quantity of energy is lost in consequence of the work which is done by the machine. For a machine can perform work only on condition that it expend energy.

To illustrate, take the case of a mechanical dreamer who would construct a water-wheel that is turned by a head of 10 cubic ft. of water; let him connect the wheel with a pump-rod in a manner such that when the water on the wheel has descended, that is, done its work on the wheel, half of the water is pumped up again to its former height (the other half being kept for other uses). It is clear that the head of water would constantly diminish and finally become so minute a quantity as to be imperceptible. But suppose that the wheel were made to pump up all the water; then the friction at the axles and in the water, concussion and the resistance of the air would soon compel the wheel to stop. That mechanical visionary will find to his cost that no work of any kind can be done unless there be a corresponding outlay of energy, that, therefore, the accomplishment of perpetual motion by mechanical means is an impossibility.

LESSON XXIV.

REVIEW.

74. Work, or mechanical labor, is measured by multiplying the force applied into its space described.

75. By means of a fixed pulley alone no mechanical advantage is gained.

76. The external resistance to be overcome by a Machine is called the Weight.

77. The force or pressure applied to a machine to move the Weight, is called the Power.

78. What is gained in Power, is lost in Space.

79. The Mechanical Advantage of a Machine is the ratio of the Weight to the Power.

80. In all systems of pulleys in which the string passes around all the pulleys, the advantage gained equals the number of strings at the lower block.

81. Any rigid rod made to turn about a fixed point or fulcrum, is a Lever.

82. There are three kinds of Levers, distinguished from each other by the position of the

fulcrum with respect to the Power and the Weight.

83. The advantage gained by the Lever $= \frac{W}{P}$.

84. The Wheel and Axle consists of a wheel and a cylinder or axle, which turn together round the same axis.

85. The advantage gained by the Wheel and Axle $= \frac{W}{P}$, or $\frac{R}{r}$, that is

$$\frac{\text{Radius of the Wheel}}{\text{Radius of the Axle}}.$$

86. The Capstan is a modification of the Wheel and Axle. Its axle is vertical, with long pole inserted to the center, which is R. The advantage gained is the same as in the Wheel and Axle.

87. A clock is a contrivance that measures time by means of a combination of wheels, moved either by a falling weight or by an expanding spring, and is regulated by a pendulum.

88. In clocks the motor force is the force of Gravity; in watches (and in clocks without weights), the motor force is the force of Elasticity.

89. In clocks the motion is regulated by the pendulum; in watches by the balance-wheel.

90. A rigid plane, inclined at any angle to the horizon, is an Inclined Plane.

91. The advantage gained by an Inclined Plane, when the force applied acts parallel to the incline, $= \frac{W}{P} = \frac{AB}{AC}$, or $\frac{\text{Length}}{\text{Height}}$; When the force applied acts parallel to the Base: $\frac{W}{P} = \frac{BC}{AC}$, or $\frac{\text{Base}}{\text{Height}}$.

92. The great law of Machines is as follows: What is gained in Power is lost in Space or Time. This law is also called the Law of Virtual Velocities.

93. *Perpetual Motion.*— If a machine, once set in motion, would move on without the help of external force, and would continue moving without losing any of its momentum, until its material were worn out, such motion would be Perpetual Motion.

PART IV.— PRESSURE OF LIQUIDS AND GASES.

LESSON XXV.

COMMUNICATING VESSELS — HYDRAULIC PRESS.

26TH EXPERIMENT.— **Fit a piece of thin board into a tumbler, as a vertical partition dividing the inside of the tumbler into two spaces. The board should not touch the bottom of the glass, but be a little above it. Now pour water into the tumbler, and there will be two horizontal surfaces of water, each having the same height. Remove the board, and in place of it immerse a wide glass tube. The two surfaces of water will again be of the same height, nearly.**

Familiar Facts.— The same may be seen in two glass tubes of unequal width (Fig. 38) which are cemented into a base made of tin, and connected with each other by means of a tin tube (*a*). Also in a teapot. The tea rises as high in the spout as in the body of the pot, and if the body were higher than the spout the tea would flow from the spout. Hence, in pouring out tea, we lift the pot and lower the spout.

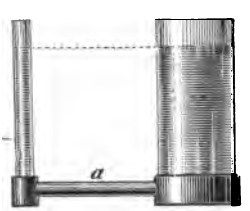


FIG. 38.

27TH EXPERIMENT.— **Take a tube** made of glass or tin and bend it so that one limb be very short, perhaps, only one-twentieth as long as the other, and let the opening of the short limb be drawn out fine (Fig. 39). Then pour water into the long tube, holding the short one closed with the finger. On removing the finger, water will jet forth. Thus we have a fountain on a small scale. If the short tube were tall enough, the water would rise until it stood at a level with the water in the other tube. The tube being short, however, the water rises in a jet, but not to that level, because there is friction, and because the returning drops depress the rising jet.

FIG. 39.

Familiar Facts.— Cisterns, offices, dwelling-houses and factories are supplied with water from large elevated reservoirs.

Vessels connected with each other so that a liquid can pass freely from one into the other, are called Communicating Vessels.

28TH EXPERIMENT.— **One end of a glass tube** is cemented into a small hollow tin ball provided with about a dozen fine openings (Fig. 40). The other end is freely inserted in a rubber ball, previously filled with water. When the

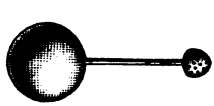


FIG. 40.

ball is pressed with the hand, the water jets forth from all the openings of the tin ball at once.

A pressure brought to bear upon a small portion of a body of liquid is transmitted equally to all parts of the liquid in all directions.

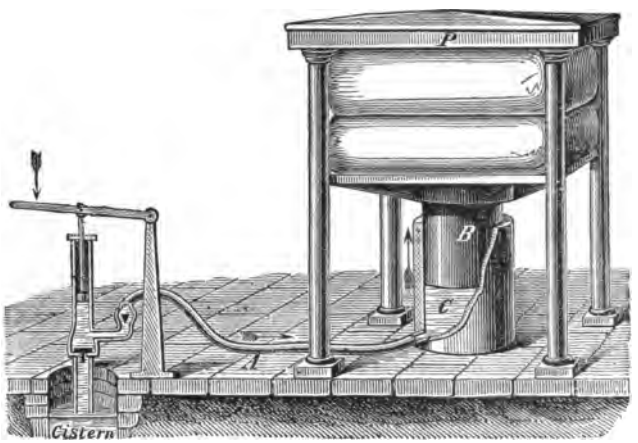


FIG. 41.

Suppose now that the cross-area of the narrow tube (Fig. 38) be one square inch; and that of the wide tube 20 square inches; and suppose that I give the water in the narrow tube a downward blow, with a piston, of the force of 50 pounds; then the upward pressure at the opening of the other tube will be 50 times 20 = 1,000 pounds. That is, the pressure of 50 pounds is exerted upon every square inch of surface; and as there are 20 square inches of cross-area, the upward pressure upon the surface of the liquid is 1,000 pounds.

Application.— Advantage has been taken of this law of equal transmission of pressure in a machine called the "Hydraulic Press," invented in 1796 (Fig. 41). By means of a lever (of the second kind) a pressure is exerted upon the water in the narrow tube, *A*. This pressure is communicated to the water in the wide tube *C*, forcing the movable cylinder *B* to ascend. Bales of cotton, or any other object to be compressed, lying on the plate, and prevented from rising by the fixed plate, *P*, are thus compressed with enormous force. Let the cross surface of the water in the cylinder be 100 times that of the water in the narrow tube, and if the pressure applied to the liquid in the tube amount only to 50 pounds, the pressure exerted upon the bale of cotton will amount to 5,000 pounds. But since the power applied by the hand may be increased tenfold with the advantage gained by a longer lever, the amount of pressure may easily be raised to 50,000 pounds. It can be further increased by steam-pressure, so that the resulting pressure may amount to over a million pounds.

The liquid generally used is water or oil. The Hydraulic pressure is one of the grandest and most useful inventions of modern times. It serves to compress bulky objects such as cotton, wool or hay; to compress seeds for the extraction of oil; to fix axles into the wheels of locomotives and railway cars; and to raise heavy loads, such as vessels or loaded cars.

LESSON XXVI.

DOWNWARD PRESSURE OF LIQUIDS — BUOYANCY.

Downward Pressure of Liquids.— We have seen that if a pressure is exerted upon any portion of the surface of a liquid, this pressure is transmitted undiminished and in all directions.

Let us imagine that the liquid in the vessel, Fig. 43, consists of an indefinite number of horizontal layers. The downward pressure which gravity

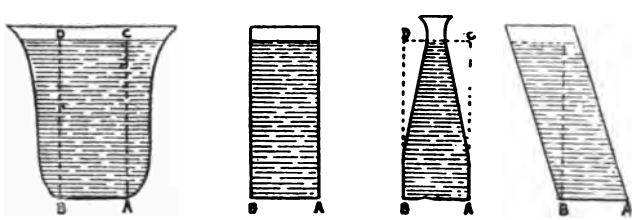


FIG. 42. FIG. 43. FIG. 44. FIG. 45.

Pressure of Liquids upon Bottom of Vessels.

exerts upon the surface layer is transmitted undiminished to the next layer below; but this layer is also subject to the downward pull of gravity, hence it will transmit its own downward pressure as well as the received pressure, to the layer immediately below; this layer, therefore, is pressed upon by the two layers above. In the same manner, the

fourth layer will be pressed upon by the three layers above, the fifth layer by the four layers above, and finally the lowest layer by all the layers above it. Hence it is evident that *the pressure upon the bottom of a vessel containing a liquid is equal to the weight of a vertical column of the liquid whose base is the area of the bottom of the vessel, and whose height is the depth* (or vertical height) *from the bottom to the surface.*

The pressure upon the bottom of vessels 42, 44, 45, is the same as the weight of the liquid column in Fig. 43.

Buoyancy of Water.— If a large empty flask be sealed up and then held immersed in water, the flask will exert a pressure against the hand, which pressure tends to make it rise to the surface of the water. This pressure is an upward pressure of the water against the flask. It is called Buoyancy. Now the flask has weight, and so has the air inside of it. The combined weight of flask and air is smaller than the volume of water the flask displaces. This is the reason why the flask tends to rise to the surface. It will *float* out the liquid; because its buoyancy is greater than its weight.

But if the flask be filled with water, and sealed up, and then immersed, it will sink. The entire volume of the flask, including the glass, if composed of water, would stay anywhere within the liquid,

for its buoyancy would be the same as its weight. The reason why it sinks is that the glass is heavier than a like bulk or volume of water. A piece of glass sinks in water.

If now the flask be filled with a heavy substance such as sand, and immersed, it will sink again, because its buoyancy is less than its weight.

The Hydrostatic Balance is an ordinary balance, each pan of which is provided with a hook, as may be seen from Fig. 46, representing one side of it. It demonstrates that *a body* suspended *in a liquid loses a portion of its weight, which portion is equal to the weight of the liquid displaced.*

A hollow cylinder, *a*, is suspended to one of the pans. Below it is a solid cylinder whose volume is precisely equal to the capacity of *a*. The whole is balanced by a weight in the other pan. If the hollow cylinder, *a*, be filled with water, the balance is no longer in a state of equilibrium. But when *b* is suspended in water, contained in a vessel as shown in the figure, the

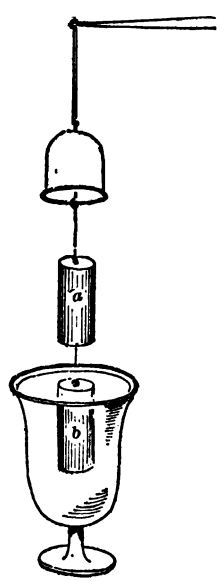


FIG. 46.
Hydrostatic Balance.

equilibrium of the balance is restored. By being immersed in this manner, *b* loses in weight, the loss being equal to the weight of the water in cylinder *a*.

Familiar Facts.— Heavy bodies can be made to float on a liquid if they are given such a shape as to enable them to displace a volume of the liquid larger than their actual volume. A lump of iron, for example, will sink when put on water; but if converted into a hollow sphere of sufficiently large volume and thin sides, it will readily float on water. A lump of iron, however, will float on mercury, because it has less weight than the same volume of mercury. Life-preservers are light bodies that slightly increase the volume of water displaced; and a person with a life-preserver attached, can therefore float on water. In fresh water dead bodies at first sink to the bottom, but after a few days rise to the surface, their decomposition having generated gases that swell the tissues and then increase their volume without altering their weight. Salt water being denser than fresh water, a vessel draws less water in the ocean than in a river; and if an ocean vessel laden to its full capacity is to ascend a river, it must first be relieved of some of its cargo. Sunken vessels, or other objects immersed in deep water, have been raised to the surface by means of barrels filled with water and attached to the vessels. These barrels had an

opening on their lower surface through which air was pumped into the barrels by means of flexible tubes. This air expelled the water from the barrels, making them lighter than they were before, after which, their buoyancy would lift both vessel and barrels to the surface.

Applications. — The hydrostatic balance furnishes a ready method for finding the volume of a body of any shape, provided it is not soluble in water. The body is suspended by a fine thread to the balance, and is weighed first in the air, and then in distilled water at 4° C. The loss of weight is the weight of the displaced water. By dividing the loss of weight by the weight of a cubic foot of water, which is 62.418 lbs., the volume of the displaced water is obtained. But this volume is manifestly that of the body itself. Suppose, for example, a body loses .62418 lbs. when weighed in water. This is consequently the weight of the water displaced. Now divide .62418 by 62.418 and we get $\frac{1}{100}$ cu. ft. or 17.28 cu. in., the volume of the body immersed.

LESSON XXVII.

SPECIFIC GRAVITY.

A marble has less weight than a leaden ball of the same volume; a pail filled with water has less weight than when it is filled with sand; a cubic foot of water is lighter than a cubic foot of iron.

Conversely, equal weights of substances often occupy unequal volumes. Thus the volume of a pound of meat is much larger than that of a pound of iron. We say of iron it is denser than meat. Of lead a smaller volume is required than of wood to make up a pound.

The density of bodies varies inversely as the volumes occupied by equal weights.

The relation between the weight of a body and the weight of the same volume of water is called the *specific* gravity — or *specific weight* — of the body.

The water taken as a standard for this purpose has a temperature of 4° C. and is chemically pure.

To say, for example, that the specific gravity of mercury is 13.6, means, that any given volume of

mercury is 13.6 times as dense or heavy as the same volume of water.

To find the specific gravity of a solid body divide the weight of the body by the weight of an equal volume of water.

Specific Gravity of Liquids.— A Specific Gravity Flask is a convenient instrument for ascertaining the specific gravity of liquids. It contains a fixed quantity of water usually 100 or 1,000 grains. Either number, of course, is the weight of a fixed volume of water.

To find the specific gravity of any liquid, we need only to balance the flask on a scale, then fill it up to the mark with the liquid under examination, and balance again, to do which the weights required are the absolute weight of the liquid. Now divide this weight by 100 or 1000, according to the capacity of the flask; the quotient = the specific gravity of the liquid.

Example: The sulphuric acid filling a 100 gram flask up to the mark was found to weigh 180 grains; find the specific gravity of the acid.

Solution: The absolute weight of the acid = 180 grains, which, divided by 100 (the weight of the same volume of water), = 1.8, specific gravity of the acid.

The Specific Gravity of Gases is usually ascertained by means of a globe of glass provided with a stop-cock. Suspend the globe from one of the scales of a balance, and establish equilibrium. Next, exhaust the air from the globe by means of an air-pump, and weigh the globe again. The weight now found is that of the globe alone; and the difference between the two weights is the weight of the volume of air that filled the globe previous to exhaustion. Now fill the globe with the gas under examination and weigh again. The additional weight required to balance the globe containing the gas = the weight of the gas. Divide this weight by the weight of the equal volume of air previously obtained; the quotient = the specific gravity of the gas.

Example: A glass globe when filled with atmospheric air, weighed 50.56 grains; when exhausted it weighed 50.16 grs.; when filled with illuminating gas, it weighed 50.4 grs. Find the specific gravity of the gas.

Solution: $(50.56) - (50.16) = 0.4$ grs., the weight of the air; and $(50.4) - (50.16) = 0.24$ grs., the weight of an equal volume of the gas. Now $0.24 \div 0.4 = 0.6$, the specific gravity of the gas.

LESSON XXVIII.

HYDRODYNAMICS.

Hydrodynamics treats of liquids in motion, and of the laws of this motion.

We have seen (Lesson XXV) that pressure upon liquids is transmitted in all directions undiminished, that consequently the pressure of gravity upon the surface of liquids is transmitted to all the layers of liquid below, and that the pressure upon the bottom of vessels containing liquids is equal to the weight of a vertical column of the liquid whose base is the area of the bottom. If, now, an opening be made near the base in the side of a vessel containing a liquid, the liquid will flow from this opening, because the continued downward pressure of gravity upon the surface of the liquid and transmitted to that layer of the liquid which lies on a level with the orifice, is transmitted also to the portion of liquid within the orifice. It is this transmitted pressure of gravity which causes the stream. The path described by the stream is a curve — if the stream issues from the orifice horizontally, the curve is a parabola — in accordance with the Second Law of Motion. The velocity of the stream, being due to gravity, is a constant quantity, provided the surface of the liquid in the vessel is kept at the same height. It is spoken of as the velocity of the

"efflux," by which is meant the space. Every particle of liquid, after leaving the orifice, passes over in one second, on the supposition that its motion during that second is uniform. The resistance of the air, however, and the friction the jet undergoes on passing through the orifice, are two important resistances which, for the sake of brevity, are neglected in this book.

The Velocity of Efflux increases with the vertical height of the liquid above the center of the orifice. This height is called the "Head."

Reaction of streams — Lawn Sprinklers. — Two horizontal tubes are pivoted at right angles on an upright tube, *a*, with which they communicate and through which water is forced. At either free end of the horizontal tubes, but on opposite sides, are small orifices, *1* and *2*. As long as these orifices are closed, the tubes *b* and *c* remain stationary, because the pressure from within, against the area of the closed orifice *1*, — which pressure would tend to move *b* in the direction of *1* — is balanced by the pressure, from within, against the corresponding area of the opposite side of the tube, which pressure would tend to move *b* in the direction of the arrow. The same reasoning applies to tube *c*.

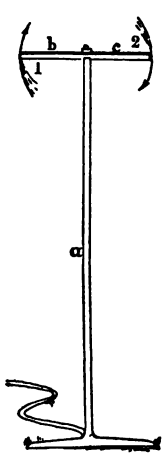


FIG. 47.
Lawn Sprinkler.

If, now, the two orifices are opened, the water will issue from them, which produces a rotation in the tubes, each tube moving in the direction opposite to that of its stream. The cause of the rotation is this: when the orifices are opened, the pressure against orifice *1*, as far as the area of this orifice is concerned, is removed, there being no surface at that place for the water to press against; but the pressure against the corresponding area on the opposite side of the tube — an area corresponding in size to the area of the opening — still continues. It is this pressure which causes tube *b* to rotate in the direction of the pressure and opposite to that of the stream. The same course of reasoning applies to the other tube. The upward flight of a sky-rocket is likewise due to reaction.

Applications. — The motive power of water is generally utilized either by means of water wheels, turbines, rams or hydraulic engines. Water wheels are of two kinds, *undershot* and *overshot*. The *overshot* wheel has on its circumference a series of buckets which receive the water flowing from a *sluice*. These hold the water as they descend on one side, and empty it as they come up on the other. The *undershot* wheel has projecting boards, at right angles to the circumference of the wheel, which receive the force of the current. The lowest float-boards are immersed in the water and thus made to revolve by the force of the current.

LESSON XXIX.

AEROSTATICS AND AERODYNAMICS.

Pneumatics.— Aerostatics is the science that treats of gases at rest; aerodynamics, the science that treats of gases in motion. The ancient term comprising both sciences is pneumatics.

Characteristics of Aeriform Fluids.— Aeriform or gaseous fluids — also called "elastic" fluids — have been divided into *gases* and *vapors*. A gas is a substance remaining gaseous at ordinary temperatures; a vapor is a substance which at ordinary temperatures is a liquid or a solid.

1. Aeriform fluids have no form or shape of their own. This is owing to their perfect expansibility, that is, to the great tendency their particles have of repelling each other.

2. They are easily compressible and highly elastic. This may readily be illustrated by means of a popgun which is placed vertically, mouth downward, on a table, its mouth being firmly closed. Push down the piston, and the air below it will be greatly compressed; let go the piston, and the compressed air by virtue of its elasticity will expand again.

3. Their density of specific gravity is very small. Air, for example, has only about $\frac{1}{770}$ the density of water.

4. All laws resulting from the elasticity and great mobility of the particles of liquids, such as the law of equal transmission of pressure or the law of efflux, are applicable to aeriform fluids, for the elasticity and mobility of their particles are greatly exceeded by those of liquids.

5. They diffuse into one another. This is owing to their great tendency to expand. The escape of an exceedingly small quantity of illuminating gas in a room, for example, will at once be noticed in all parts of the room, showing that the gas diffuses itself through the whole body of air in the room.

6. They may be absorbed by solid and liquid bodies. It is well known that a piece of charcoal, for example, can absorb a large volume of air, or of ammonia vapor; and that water contains air which, when the water is heated, is seen to escape.

Air and the Atmosphere.— A mixture of two gases, oxygen and nitrogen, constitutes what we term "air;" and the aerial ocean surrounding the entire globe is called the Atmosphere. The height of the atmosphere is not definitely known. Its base is at the surface of the earth. It contains small quantities of other gases such as carbonic acid gas and water vapor; but 100 volumes of atmospheric air consist everywhere of about 21 volumes of oxygen and 79 volumes of nitrogen. Although air itself is invisible, its presence may be demonstrated by lowering an inverted tumbler ver

tically into a body of water. The air so confined maintains its place to the exclusion of the water, allows itself to be compressed more and more as the tumbler is pushed farther down, and expands again when the tumbler is raised. The fact, then, that air possesses at least three properties of matter, and that it has weight, are evidence it is a body. Its presence can be distinctly felt when air is in a state of motion, which state, according to the degree of its rapidity, is known as wind, storm, or hurricane. Air is colorless; but to an observer on the earth the atmosphere on a clear day appears blue. A similar appearance of color manifests itself when we look at a large body of water such as a lake, while a small quantity of the same water is devoid of color.

Although air is a very light body, and endowed with great expansive force, it does not diffuse itself into space, every particle of it being held by the force of gravity of the earth. The upper layers of the atmosphere exert a downward pressure upon the lower layers near the surface of the earth; and as air is a highly compressible body, the lower portions of the atmosphere are greatly compressed, in other words, very much denser than the upper portion. This is borne out by the fact that when a bladder containing air from the lowlands is taken up on a mountain it swells gradually, and finally will be distended to its full capacity. Air, therefore, is densest at the level of the ocean.

Weight of Air — 29TH EXPERIMENT.— **By means of an** air pump, exhaust the air from a globe of glass provided with a stop-cock, Fig. 48. When the exhaustion is complete, close the stop-cock; attach the globe to one arm of a balance, and counterpoise it. Now open the stop-cock; the globe will fill with air, the equilibrium be disturbed, and in consequence of the weight of the air in the globe, the globe will sink.— To restore equilibrium, additional weights must be placed on the other side of the balance; these weights indicate the weight of the air in the globe.

FIG. 48. Glass Globe With Stop Cock.

Water has been found to be 770 times as heavy as a like volume of air.

Since air has weight, it must exert a pressure upon all objects at the surface of the earth.

30TH EXPERIMENT.— **A tumbler filled** with water to the brim, with a piece of paper placed over it, is inverted. (See Fig. 49.) The hand on the paper, after pressing the latter firmly against the tumbler, is removed, but the water does not flow out. How can this be accounted for? The air evidently presses *upward* against the paper. It is this

FIG. 49.

upward pressure of the air, which supports the paper (and the paper supports the water), else the air would force its way into the water, by rushing up along a part of the inner side of the tumbler, leaving the water to fall down on the opposite part.

31ST EXPERIMENT.— **Immerse a tumbler horizontally,** in a bowl of water, and press it down gradually. It will fill with water, and afterward be entirely below the surface of the liquid. Now turn it bottom upward, and then without raising its mouth above the surface, lift it as high as possible. The whole tumbler is still filled with water, and will remain filled, although the water in two communicating vessels ought to have the same height (Lesson XXV.). The tumbler contains no air, but the air over the remaining water presses *downward* upon the water. This *downward pressure* of air supports the column of water in the tumbler.

32ND EXPERIMENT.— **Let a vessel be filled** with water; then take a narrow glass tube, open at both ends, and immerse it perpendicularly in the vessel. The tube will be partly filled with water; if taken out, the water will flow through the tube and fall, because attracted to the earth. Place the tube again in the vessel with water, but on slowly removing it, be sure that you keep the upper opening closed with the thumb. No water will flow from the tube,

because air presses against the lower opening and thus supports the column of water in the tube. On removing the thumb the water will flow out, because in this case the air presses as strongly above as it does below; the water consequently obeys the force of gravity and falls. Now fill the glass tube again; hold it obliquely, until it is in a horizontal position; the water will still remain in the tube. (Fig. 50.)

FIG. 50.

This shows that *air presses not only upward, downward, and laterally, but in all directions.*

In the preceding two experiments, a column of water was sustained by the downward pressure of air. Air, water, and all other fluids, exert pressure in all directions, while solid bodies exert downward pressure only. But downward pressure means weight; hence fluids and solids (that is, all bodies) have weight; while fluids have, besides weight, pressure in all directions.

Familiar Facts. — **From an open faucet** in a full barrel with its bung-hole closed, the liquid does not

flow, because the air presses against the opening in the faucet. *To draw vinegar*, or any other liquid from a barrel, plunge a long tube into the liquid; close the upper end with the thumb and withdraw the tube. The liquid in the tube will not flow out as long as the thumb closes the upper end. *Oil-cans* must be opened above to obtain a ready flow.

Application.—The Barometer (see next Lesson). Pneumatic Railway.

A vacuum is a space devoid of air. If water be drawn up with the mouth through a straw or glass tube, the muscular action of the mouth removes a portion of the air in the tube. The tendency of the action is to form a vacuum; but none forms because the liquid rushes up to fill the vacuum. Something similar takes place when the mouth of a syringe is held in water and the piston is drawn up.

A rarefied space is a space containing air that has less pressure than atmospheric air. A rarefied space may be obtained by removing only a portion of the air contained in a given space. If, for example, I remove half the quantity of air from a short glass tube by squeezing the rubber cap of a "drop," between the fingers, and then close the open end of the tube with a finger, and release the rubber cap from any pressure, the air left in the tube and

cap has *less* pressure than before, because a portion of it has been withdrawn. To prove this, place the end of the glass tube in a liquid and remove the finger; the tube will fill with a volume of the liquid equal to the volume of the air removed.

The Measurement of the Elastic Force of Gases.— Bend the closed end of a long glass barometer tube into a short vertical arm, and pour just enough mercury into the tube to fill the bend. The air inclosed in the short arm is now in its natural condition, that is, under the pressure of one atmosphere. (One atmosphere is equal to 15 lbs. pressure. See next Lesson.) If thirty in. of mercury be now poured into the long arm, the confined air will be under the pressure of two atmospheres, one of air and one of mercury, and will be reduced in volume one-half. If thirty inches more mercury be added, the pressure will be three atmospheres, and the volume will be reduced to one-third. And so on, for every like increase of pressure, the volume will be reduced to one-fourth, one-fifth, etc. Therefore,

The volume of a given weight of air is inversely as the pressure to which it is exposed.

LESSON XXX.

THE BAROMETER.

In the two preceding experiments the downward pressure of air supported a column of water in a tumbler, or in a glass tube. Nothing was said, however, concerning the height of the liquid column. But we know with certainty, that if a pump could be made with perfect valves it might raise a column of water nearly 34 feet high. That is to say, the pressure of the atmosphere might support a column of water about 34 feet high.

But what if, by the same pump, we had to lift a fluid which has greater specific gravity than water, say liquid tar, or mercury? Would the atmosphere be competent to support, *e. g.*, a column of mercury 34 feet high? The answer is: No. Such a column weighs more than a column of water of the same thickness; hence its height must be less. The following imaginary experiment may show this: On each scale-pan of a balance place a tall vessel 34 feet high, but only one square inch across. Both vessels are to have equal weights; hence the beam of the balance will remain horizontal. Now, fill one of them with pure water to the height of 34 feet, and the other with mercury until it balances the water;

the mercury will then be found to be nearly 30 inches high. We have now two columns of equal weight and thickness, but of different heights. The specific gravity of the mercury is 13.6, and the height of the column of mercury = 34 feet divided by 13.6 = 30 inches.

But it was stated above, that the atmosphere could support a column of water no higher than about 34 feet; consequently, the atmosphere must be competent to support a column of mercury of equal weight, that is, a column of mercury about 30 inches high.

In order to test this reasoning, take a glass tube about 36 inches long, closed at one end; fill it with mercury, close the open end of the tube with the finger, and invert the tube into a small cup or basin containing mercury. On withdrawing the finger, it will be found that the mercury remains suspended in the tube to the height of about 30 inches (see frontispiece, first figure to the left). The space over the top of the mercury is entirely empty; it is a vacuum. We have here the weight of a column of mercury completely balanced by a column of air of the same weight but of indefinite height. Any change in the weight of the air will be instantly followed by a corresponding change in the weight of the column of mercury.

From the preceding it appears, 1st, that a column of water 34 feet high, or one of mercury 30 inches

high, nearly, can be supported by the pressure of a column of air; 2nd, that the weight and thickness of both columns are the same, while the height of the column of air has not yet been determined; 3d, that any change in the pressure of the atmosphere must produce a corresponding change in the height of the column of mercury.

The Barometer is an instrument for ascertaining the pressure of the air. Its ordinary form is that of an inverted tube (see frontispiece, center figure), with its open or lower end either bent upward a few inches, or immersed in a small cistern filled with mercury. This end may be in a wooden or metallic case containing a fine opening for the air to penetrate to the mercury. The height of a fluid in a barometer is the same, whether the instrument be in the open air or within the house. For air presses in all directions; any difference in pressure, therefore, would immediately be equalized.

Amount of Pressure of Air.— In the experiment indicated above, a weight of 15 pounds may, at the level of the sea, be substituted for either column without seriously disturbing the balance. Thus a column of mercury one inch square and 30 inches high, or one of water one inch square and 34 feet high, weighs 15 pounds. Consequently, the column of air which can support either — that is, one which is one inch square but reaches to the top of the atmosphere, also weighs 15 pounds.

Uses of the Barometer.— The atmosphere is an ocean surrounding the earth. Its pressure, therefore, must be greatest at its greatest depth, viz.: at the level of the sea. It will be gradually diminished as we ascend in a balloon, because, in this case, we leave air below us which does not press upon the mercury in the balloon. The mercury of the barometer actually falls in proportion to the elevation to which it is taken. Hence *the barometer is used for measuring the heights of mountains.*

If the records of the barometer at different places, but at identical times, be compared, probabilities may be obtained in regard to the weather which we are about to have. Thus, if a surplus of air exists at *A* and *B*, the air in these localities has more weight, and the barometer will stand high; at once a quantity of air will be conveyed to some distant place *C* where the quantity of air is deficient, that is, where the barometer stands low. If the records show that at *C* the air was previously moist and warm, while at *A* and *B* it was cold, the probabilities for *C* are clouds or rain. Hence *the barometer is used to some extent for ascertaining the weather that is about to follow.*

LESSON XXXI.

THE AIR-PUMP.

The purpose of an air-pump is to deprive a receiver, or any closed vessel, of a portion of or all the air (or gas) it contains. The principal parts of an air-pump are: (1) A *pump*, *A* (Fig. 51), communicating with the receiver *g*, the air of which is to be exhausted. *C* is a hollow cylinder; it contains a piston *K*, that can be raised and lowered, and which is pierced, the aperture being covered by a valve above *L*. This valve opens from below upward. Another valve at the level of *C* covers the tube connecting the pump and the receiver; it also opens from below upward. The contrivance *n b* — a stop-cock and a barometric column — is not indispensable; when it is not required for an experiment, *n* is closed; in the simpler form of air-pumps the contrivance *n* is wanting altogether.

At the instant when the piston is raised, valve *L* remains closed on account of atmospheric pressure; space *A C* below the piston is increased, and the air in this space begins to have less pressure as the piston rises, because it is made to occupy a greater space. Hence the air in *g* expands and passes, forc-

ing valve *C* open, into the space below the piston. This action continues until the piston arrives at the

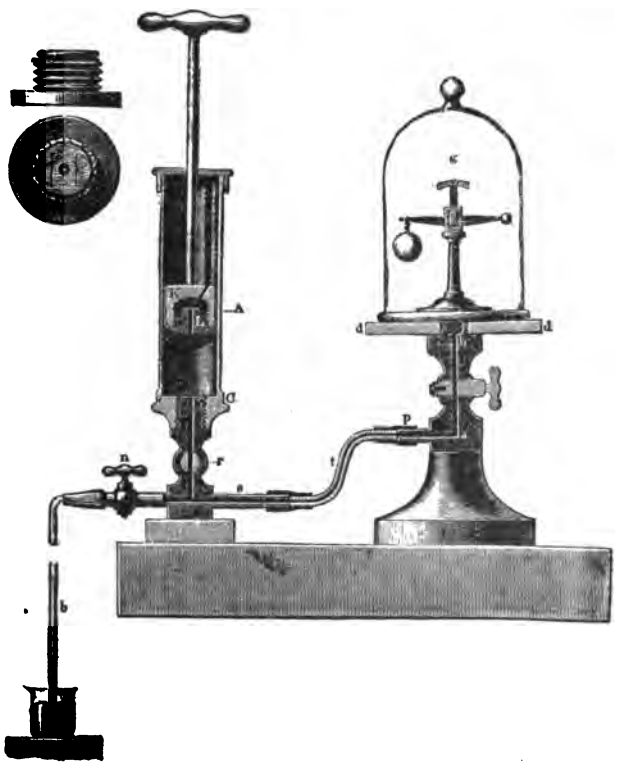


FIG. 51.
Air-pump.

top of the cylinder. At this instant, valve *C* sinks again. (The air which was above the piston escaped during the upward stroke through an opening in the

top of the cylinder, not visible in the wood-cut.) The piston is now made to descend; the air between it and valve *C* is compressed, forcing valve *L* open. The piston finally arrives at the base (*C*) of the cylinder, and the same process of raising and lowering it is renewed. By the action of the piston, then, the air in the receiver is rarefied, and a part of it ejected from the pump whenever the piston rises.

Experiments with the Air-Pump.

33RD EXPERIMENT. — **The Magdeburg Hemispheres**, so called from *Otto von Guericke*, burgomaster of Magdeburg, who exhibited them in 1654. Both hemispheres (Fig. 52) together form a sphere provided with a handle at each pole. When using them, one handle is removed and an open stop-cock put in its place, which is screwed on the plate of an air-pump. If, now, the sphere is exhausted, the stop-cock closed, the whole detached from the air-pump, and the handle attached to the stop-cock, it will require a great effort to separate

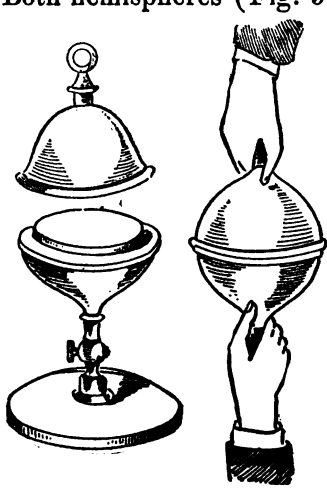


FIG. 52.
Magdeburg Hemispheres.

the hemispheres from each other. Open the stop-cock and remove the handle from it; the hemispheres may now be separated with ease. When they were exhausted, the pressure of air from without forced them together; when air was readmitted this external pressure was counteracted by the same pressure within, and consequently they came readily apart. If we suppose the vacuum to have been perfect, and the external area of the entire sphere = 50 square inches, then the external pressure of air upon the sphere amounted to 50.15 = 750 lbs.; and it required a pull of just a little more than 750 lbs. to separate the hemispheres.

34TH EXPERIMENT.— The guinea and feather tube is an apparatus to show that in a vacuum bodies fall with the same rapidity because the disturbing force of the air is removed. The apparatus consists of a glass tube, which should be at least six feet long, with a metallic cover over one end and provided with a stop-cock at the other. The tube contains minute specimens of substances of unequal densities, such as grains of metal and bits of paper or a small feather. The tube is screwed upon the plate of the air-pump, exhausted, closed by means of the stop-cock, unscrewed, removed and then quickly inverted; the substances within are seen to fall together and to arrive at the base of the tube together. —Invert the tube again, but during the fall of the substances admit a small quantity of air

by quickly opening and closing the stop-cock; it will be noticed that the light bodies are from this moment retarded in their fall. — Finally, open the stop-cock and leave it open; invert the tube rapidly, as before; the light bodies will fall more slowly than before. All this shows that the resisting force of the atmosphere retards bodies falling at the surface of the earth *unequally*, that is, light bodies more than heavy ones.

35TH EXPERIMENT.—**Place a small receiver** over a shriveled apple on the plate of an air-pump and exhaust. As exhaustion progresses the apple is seen to expand and finally assumes its original full and round shape. But if air be admitted, the apple will shrink again. Similar results are obtained with an empty bladder.

36TH EXPERIMENT — *The Mercury Shower.*— **A wooden cup,** through the bottom of which passes a plug of hard wood, generally oak, is placed upon a receiver with a tumbler below. If mercury be now poured into the cup, and the air exhausted, the atmospheric pressure will force the mercury through the pores of the plug.

37TH EXPERIMENT.— **An empty test-tube** — or a so-called *Bolt-Head*, as in Fig. 53 — is placed inverted in a tumbler which contains water. A receiver being put over the whole, and exhaustion

commenced, it will be seen that air passes in bubbles from the test-tube through the water into the space under the receiver, until the pressure of the air in the tube = the pressure of the air outside of the tube. When air is introduced into the receiver, water rises from the tumbler into the tube and remains there, being supported by atmospheric pressure.

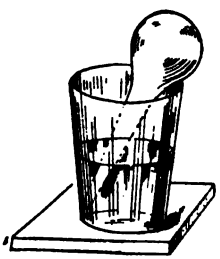


FIG. 53.
Inverted Bolt-head.

38TH EXPERIMENT.— **A tumbler filled** with water is placed under a receiver. During exhaustion the air absorbed in the water will expand, and appear as small globules at the surface and on the inner sides of the vessel.

Familiar Facts.— Burning bodies are extinguished when deprived of air. A burning candle, for example, under the receiver of an air-pump, will go out after exhaustion for want of the necessary oxygen to support its combustion. It is the same with living animals. Place a mouse upon the plate of an air-pump — after loosely covering the aperture of the plate, as a precautionary measure,— and put a receiver over it. Then exhaust; the mouse will gradually lose vitality, and if the rarefaction of air is sufficient, it will die for want of the oxygen necessary to support life. Whenever

combustion takes place, oxygen is consumed. There can be no combustion without the presence of this gas. Now the breathing of an animal is a process of combustion, by which, as in all combustion, the oxygen is converted into carbonic acid gas which is unfit for respiration. If this conversion were to continue for ages, the atmosphere would gradually be filled with this noxious gas, lose its oxygen, and thus become unfit for the breathing of animals. Fortunately this calamity is averted by the fact that plants use up this carbonic acid gas, setting its oxygen free again. The quantity of oxygen in the atmosphere always remains the same; this would show that the action of the animal kingdom is neutralized by the reverse process that takes place in the vegetable kingdom.

LESSON XXXII.

COMMON PUMP.

39TH EXPERIMENT.— **Instead of immersing** the end of a glass tube, as we did in Lesson XXIX., let us dip a syringe into water. On drawing up the *piston* by means of the *piston-rod*, the liquid is seen to rise in the syringe. This is explained by the law given in Lesson XXIX., for the piston being air-tight, it leaves, as it rises, a vacuum below it, which is eagerly filled by the water. But what causes the water to rise? The answer is: The pressure of air on the surrounding water.

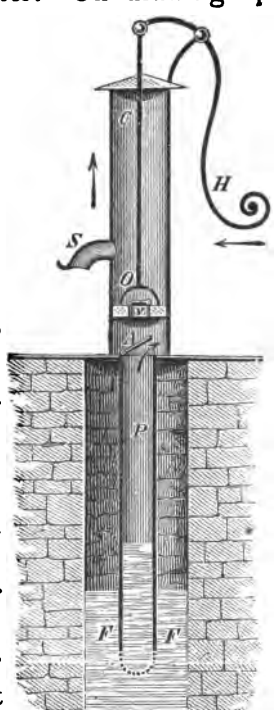


FIG. 54.

This principle is applied in the Common Pump. When we look at a pump (Fig. 54) the first thing that strikes our eye is the *cylinder*, or *barrel*, *C*, the *spout*, *S*, and the *lever* or *handle*, *H*. The lower part of the barrel, *P*, is called the

suction-pipe; it is submersed in the water. Inside of the barrel works a piston *O*, which fits air-tight, and can be moved up and down by means of the piston-rod to which it is attached. It is pierced with a hole, and the hole is covered by a valve, *v*, which opens upward. The piston-rod is connected at the top with the lever *H*.

When the handle of the pump is raised, and has arrived at its highest point, the piston is at its lowest, resting on valve *A*.

When the handle is forced down, as in Fig. 54, *the piston rises;* next, valve *A* opens. But what causes this valve to open? The answer is: When the piston rises, the air previously confined between valve *A* and the level of the water in the suction-pipe now occupies a larger space; hence it is rarefied, and has less pressure than the air over the outside water *F F*. The result of these unequal pressures is, that the level of *F F* is lowered by the pressure of the atmosphere over it, and that the water in the suction-pipe *P* must rise until the air inside of the tube has reached the same pressure, nearly; that is, the same degree of density as the outside air. At this instant, valve *A* will close — that is, it will fall of its own weight. It is evident that valve *v* remains closed whenever the piston rises.

When the piston is lowered, valve *v* is forced open, because the air below the piston is com-

pressed, and the expansion of the compressed air opens valve *v*. When the piston is at its lowest this valve falls by its own weight. On raising the piston-rod the second time, more air is withdrawn from the suction-pipe; water commences rushing up, and enters through valve *A*. On lowering the piston again, it descends into the water, and from this moment all the air below the piston is expelled. Some water is now above the piston, and the lower valve again falls of its own weight. After this, whenever the piston *descends*, a large quantity of water passes through the piston valve *v;* whenever it *rises*, that quantity of water remains on the top of the piston-valve. At every subsequent rise of the piston, the water above it flows out through the spout.

The main principle of the pump is the fact that the *pressure of the air upon a body of water, causes the water to rush up into a vacuum formed in a tube communicating with that body of water.*

The column of water in the suction-pipe, between the level of *F F* and valve *V*, is supported by the pressure of the air on the water in the cistern.

LESSON XXXIII.

FORCE PUMP.

A common pump cannot draw water to a vertical height of 34 feet, because its vacuum cannot be made perfect.

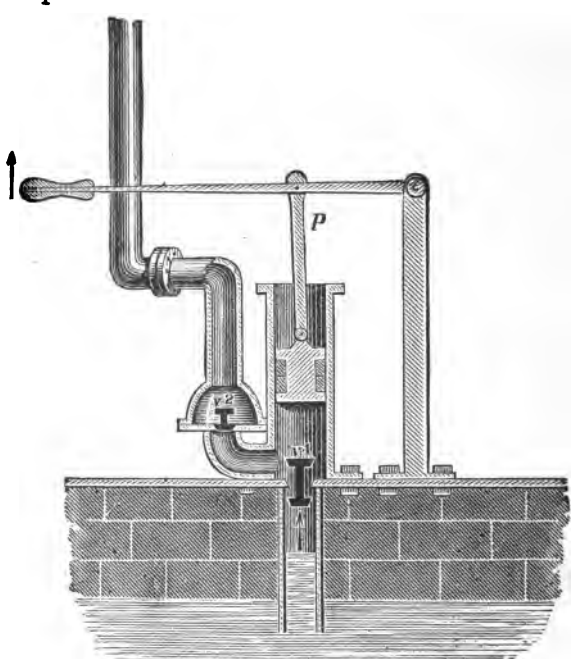


FIG. 55.

In order to raise water to a greater height, the *Force Pump* is used (Fig. 55). It is constructed

on the same principle as the Common Pump; it differs from the latter in the following three points: 1. The piston of the Force Pump is *not pierced*. 2. In place of the spout there is a tube at the lower part of the barrel, which leads to the place where the water is to be carried. 3. That tube contains a valve, v^2, which opens outwardly.

When the piston P is *raised*, this valve is closed; thus the air below the piston becomes rarefied, and water is drawn through the lower valve v^1, the same as in the common pump. When the piston *descends*, the lower valve is closed on account of its own weight; the water above the valve v^1 is then forced through valve v^2 into the tube, from which it cannot flow back.

A hand Fire-Engine, such as Fig. 56, consists of an *Air-chamber*, N, and of *two Force Pumps* to pump water into it. Both pumps stand in a large box filled with water. Two iron levers (called *brakes*) L and L', work the iron piston rods P and P'. A wide cylinder, N, stands between the two pumps. It contains air, and a metallic tube which nearly reaches to the bottom and is open at the top. This cylinder acts like a Heron's Fountain; but in the Fire-Engine and in other pumps it is called an *Air-Chamber*. The tubes of the Force Pumps enter the air-chamber; each has a valve opening outwardly into the air-chamber.

When *A*, *one of the pistons*, *rises*, the valve of tube *B* is closed by the pressure, which the air over the water in the air-chamber exerts. Water, at the same time, enters from the box through the lower valve *C* into the barrel of the pump.

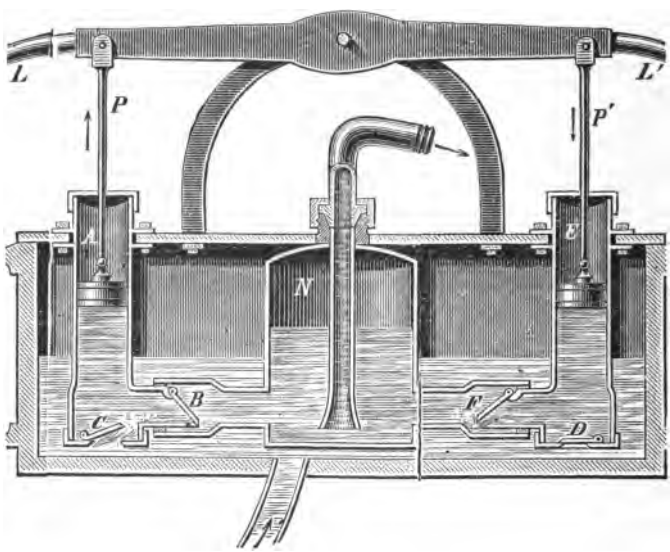


FIG. 56.

Why? When the piston *E descends*, the lower valve *D* closes of its own weight, and water is forced into the air-chamber through the valve of the tube *F*. After continued pumping, the water in the air-chamber has risen so high that it has concentrated and compressed the air into

a much smaller space. But from Lesson VI we see that the more we compress air, the greater its expansive force. Hence it is evident that the jet of water sent forth from the metallic tube is sent forth by the expansive force of the compressed air in the air-chamber. There being two pumps and an air-chamber, the jet is continuous.

Give the difference between the Common Pump and the Force Pump.

Also, between a Heron's Fountain and the Air-Chamber of a Fire-Engine.

The Common Pump and Barometer Compared

Four points in common:—

1. Both have a *tube* or *cylinder*.

2. Both have a *vacuum*.

3. In both, the liquids rise in consequence of *the pressure of air*.

4. In both, the liquids can not rise higher than the *capacity* of that pressure permits.

Eight points of difference:—

1. The *Barometer* has a *glass* tube; *pumps* have iron or wooden tubes.

2. The *barometer tube* is *closed* above the vacuum; the pump cylinder has a *valve* above the vacuum.

3. The vacuum in the *pump* can never be made as *perfect* as that in the *barometer*.

4. The *pump-vacuum* must first be *produced;* the *barometer-vacuum*, once established, *remains*.

5. The liquid in the *barometer* is always *mercury;* in the *pump* it may be water, oil, vinegar, or most any other liquid.

6. In the *barometer* neither spout nor lever is required.

7. *No graduated scale* is attached to the *pump*.

8. The liquid column in the barometer usually stands no higher than 30 inches. The liquid column in the pump stands higher than that of the barometer (Comp. Lesson XXX.). Thus when the mercury in a barometer reads 29.5 inches, this number is an index of the pressure of the air at the time; and in a common pump with perfect valves, the water could then be drawn up $29.5 \times 13.6 =$ 401.2 inch. = 33.4 feet.

The distance between the level of the water in the cistern and the lower valve must be proportionate to the capacity of the pump. Suppose, for instance, it were forty feet in the imaginary pump previously mentioned, then the water would not come up to the lower valve, because the atmospheric pressure cannot lift a column of water higher than its natural limit.

LESSON XXXIV.

THE SIPHON.

The siphon is a bent tube open at both ends, used for transferring liquids from one vessel to another, always from a higher level to a lower. The shape of the bend is immaterial; nor need one arm be longer than the other. It is essential, however, that the surface of the liquid to be transferred be higher than the free end of the siphon, otherwise the siphon will not operate.

Let tube *A B D*, Fig. 57, represent a siphon, through which the liquid may be drawn at *A* by suction; or the tube may be first filled with the liquid, and, while full, placed as indicated in Fig. 57. In this position, the free end of the siphon is on a level with the surface of the liquid in the vessel, and, although the tube remains filled, it will not run. The reason of this is, that the pressure of the atmosphere at *D* and at *A* is equal but opposite. Atmospheric pressure at *D* (that is, at the surface of the liquid and transmitted to *D*), tends

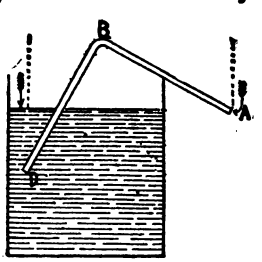


FIG. 57.
Siphon.

to force the liquid column in the direction $D\,B$, while the atmospheric pressure at A tends to force it up $A\,B$. The vertical height of both columns is the same; consequently the resistance offered to the atmospheric pressure at A and D is the same.

If A be lowered, the siphon will run, and continue to run as long as A is below the surface of the liquid in the vessel. For in this case, atmospheric pressure at D is greater than at A; the liquid, therefore, is forced through the tube in the direction $D\,A$. The reason why atmospheric pressure at D exceeds that at A is readily explained by means of Fig. 58, where tube $A\,B\,C\,D$ represents a siphon whose arm $A\,B$ is usually, but not necessarily, longer than arm $C\,D$. Atmospheric pressure, which we will suppose $= H$, on D tends to drive the liquid up $D\,C$; at C the amount of this pressure $= H - D\,C$. This means that the atmospheric pressure, H, is diminished by the weight or downward pressure of a vertical liquid column, $D\ C$. The atmospheric pressure on the other side is exerted on A, in the direction $A\,B$, and at B it amounts to $H - A\,B$. Since $D\,C$ is a shorter vertical column than $A\,B$, it offers less resistance to H, hence H, the

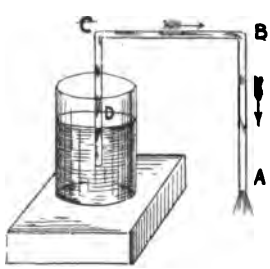


FIG. 58.
Siphon.

atmospheric pressure, is greater at D than at A, and consequently the liquid would flow in the direction $D\ C\ B\ A$. In other words, at the same level $B\ C$, two unequal pressures act on the liquid in opposite directions, and their difference is $H - D\ C - (H - A\ B)$, or $A\ B - D\ C$, acting from D towards A. If A be raised until it is higher than the surface of the liquid in the vessel, the liquid in the siphon will flow back into the vessel, because in this case $D\ C$ is greater than $A\ B$, that is, the difference of the pressures on the liquid in $B\ C$ is $D\ C - A\ B$, acting from A towards D.

If $D\ C$, or the top of the bend, were at a height greater than the barometric height of the liquid above the level in the vessel, there would be found a barometric vacuum in the upper part of the siphon, and the siphon would not operate, nor would the siphon flow in a vacuum.

In order to obtain a constant flow it is very convenient to let the siphon float on the liquid to be transferred, in which case it will descend with the liquid and not change its position with reference to the surface of the liquid in the vessel and that at the free end A.

It will now be well for the student to make a drawing of (1) a *barometric column* of mercury and

its cistern, (2) a *common pump* with which mercury is drawn up from the cistern, and (3) a *siphon* through which mercury is transferred from a higher level of mercury to a lower; the three drawings to be by the side of each other, the same horizontal line passing through the surface of the liquid in the three cisterns. Assume the barometer to stand 28 inches high at the time.

LESSON XXXV.

REVIEW.

94. Vessels connected with each other, so that a liquid can pass freely from one into the other, are called Communicating Vessels.

95. A pressure brought to bear upon a small portion of a body of liquid is transmitted equally and undiminished to all the parts of the liquid in all directions.

96. The Hydraulic Press serves to compress bulky objects such as cotton, wool or hay; to compress seeds for the extraction of oil; to fix axles into the wheels of locomotives and railway cars, and to raise heavy loads, such as vessels or loaded cars.

97. The pressure upon the bottom of a vessel containing a liquid is equal to the weight of a vertical column of the liquid, whose base is the area of the bottom of the vessel, and whose height is the depth (or vertical height) from the bottom to the surface.

98. The Buoyancy of a liquid is its upward pressure.

99. The hydrostatic Balance demonstrates that a body suspended in a liquid loses a portion of its weight, which portion is equal to the weight of the liquid displaced.

100. The density of bodies varies inversely as the volumes occupied by equal weights.

101. Specific gravity — or specific weight — is the relation between the weight of a body and the weight of the same volume of water.

102. To find the specific gravity of a solid body, divide the weight of the body by the weight of an equal volume of water.

103. The specific gravity of liquids may be ascertained by means of Specific Gravity Flasks.

104. The specific gravity of gases is usually ascertained by means of a globe of glass provided with a stop-cock.

105. Hydrodynamics treats of liquids in motion, and of the laws of this motion.

106. The velocity of efflux increases with the vertical height of the liquid above the center of the orifice. This height is called the Head.

107. Aerostatics is the science that treats of gases at rest; Aerodynamics, the science that treats of gases in motion. Both were formerly called pneumatics.

108. Aeriform fluids are divided into gases and vapors.

109. A gas is a substance remaining gaseous at ordinary temperatures. A vapor is a substance which at ordinary temperatures is a liquid or a solid.

110. Aeriform fluids have no form or shape of their own.

111. Aeriform fluids are easily compressible and highly elastic.

112. The density or specific gravity of aeriform bodies is very small. Air has only about $\frac{1}{770}$ the density of water.

113. Aeriform fluids diffuse into one another.

114. The atmosphere is the aerial ocean surrounding the entire globe.

115. Atmospheric air is composed of two gases; oxygen and nitrogen, mixed in the proportion of 21 volumes of the former and 79 volumes of the latter.

116. Air presses in all directions.

117. A vacuum is a space devoid of air.

118. A rarefied space is a space containing air of less pressure than atmospheric air.

119. The downward pressure of air can support a column of any other fluid, and the height of this column depends upon the specific gravity of the fluid.

120. A column of air extending from the earth to the top of the atmosphere will support a column of mercury about 30 inches high.

121. The downward pressure of the air is nearly fifteen pounds to the square inch of surface.

122. The barometer is an instrument for determining the pressure of the air.

123. The uses of the barometer are, *first*, to measure the heights of mountains; *second*, to assist in ascertaining the weather about to come.

124. The purpose of an air-pump is to deprive a receiver, or any other closed vessel, of a portion or all the air or gas it contains.

125. The Magdeburg Hemispheres serve to demonstrate the pressure of air. They were first exhibited in 1654.

126. The "Guinea and Feather" Tube is an apparatus to show that in a vacuum bodies such as grains of metal, bits of paper and a small feather fall with the same rapidity.

127. The principle applied in the common pump is the pressure of air forcing water into a vacuum formed over part of its surface, that is, in a tube communicating with that body of water.

128. The same principle is applied in the Force Pump and the Barometer.

129. The Siphon is a bent tube open at both ends, used for transferring liquids from one vessel to another, always from a higher level to a lower.

PART V. — MAGNETISM.

LESSON XXXVI.

MAGNETISM AND MAGNETIC ATTRACTION.

40TH EXPERIMENT.— **Suspend an iron nail by a string. The direction of the string will be vertical. But if we bring a magnet near the nail, the nail will swing toward the magnet. When near enough, the nail will attach itself to the magnet, and, if separated from the string, will not fall. This is owing to** *Magnetic Attraction.*

In place of the nail suspend the magnet by a string, and lay the nail on the table. Holding the suspended magnet over the nail, steadily bring it near the latter; the nail will eventually rise and adhere to the magnet.

The preceding shows that *magnets and unmagnetic iron attract each other.*

Magnets are of two kinds — natural and artificial. The natural magnet is an iron ore, called loadstone, which has the property of attracting iron or steel. It, also, will attract cobalt or nickel. The artificial magnet is a steel bar, either straight or shaped like a horse-shoe, which has acquired the power possessed by the loadstone.

41ST EXPERIMENT.— **Take a magnet and hold it near bits of paper, wood, cork, copper, tin, mercury. It will be found that the magnet has no attraction for these substances.**

42ND EXPERIMENT.— **If iron filings be placed on a piece of paper or glass, and a magnet be held beneath, the iron will be attracted by the magnet, notwithstanding there is something between the filings and the magnet; and the little particles will arrange themselves in curves about the end of the magnet. Magnetic attraction, like attraction of gravity, is independent of intervening bodies and spaces.**

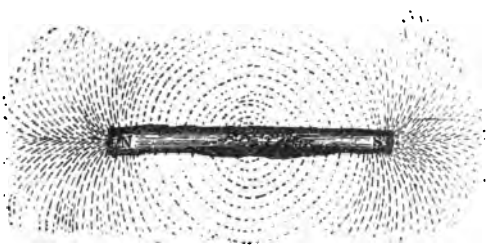


FIG. 59.

Fig. 59 represents a magnetic field. The space surrounding the magnet, and through which the magnetic force acts, is called the magnetic field. The directions which the iron filings assume are called the lines of force. They are assumed to flow from the north to the south pole, outside of the magnet, and in the opposite direction inside the magnet, so as to form complete circuits.

43RD EXPERIMENT. — **Let the magnet be placed horizontally in the iron filings and turned round several times. On withdrawing it we find that it is covered at the ends with long threads of the filings, while toward the middle they become shorter, and in the center of the magnet there is no attraction whatever.**

From this we see that the *attractive power of a magnet resides chiefly at the ends of the magnet*, and that the attraction has been neutralized at the middle.

44TH EXPERIMENT. — **The ends of a magnet are** called its poles. Tie a string to the center of a bar magnet, and suspend it from the hand. The magnet will vibrate until it finally takes a certain position, which it keeps. If disturbed, it will again vibrate, and after many vibrations, resume the same position. It will do so whether in the room or out of doors. On examining its direction, we find it pointing north and south. That end of the magnet which points north is called the *north pole* of the magnet; that pointing south, its *south pole*.

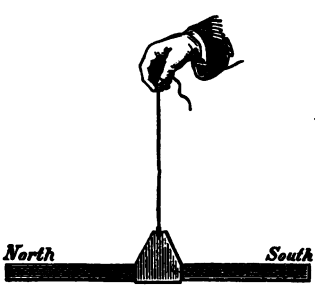


FIG. 60.

A freely suspended bar magnet points north with one end; south, with the other.

45TH EXPERIMENT.— **Bring the north pole of a** magnet near the north pole of a freely suspended magnet; this north pole will be repelled. Now, if the two south poles are brought together, they also repel each other; but when the north pole of the one is near the south pole of the other, there will be mutual attraction between these unlike poles.

Like poles repel, unlike poles attract each other.

Magnetic Induction — Iron and Steel. — Let a thin short iron rod be held in a vertical position and bring a strong magnet near the upper end of the rod. While the magnet is close up to the rod, the rod is rendered a magnet and its lower end attracts iron filings. Remove the magnet; the filings will drop and the rod cease to be a magnet.

The same may be shown by causing a few tacks to adhere to a strong magnet so as to form a series or chain. Each little tack while so adhering is of itself a magnet; its poles lie against opposite poles; in other words the poles of the whole chain of little magnets lie in the same direction. As soon as the tacks are removed from the magnet, they will no longer adhere to each other.

A piece of soft iron remains a magnet only so long as it is in contact with, or quite near to, the source of its magnetism.

It is entirely different with steel. If those tacks had been made of hardened steel, their contact with, or nearness to, the magnet would have converted them into permanent magnets.

46TH EXPERIMENT.— Take a bar of hardened steel and stroke it from end to end, on all sides, with one pole of a strong permanent magnet of steel or loadstone. The stroking must always be in the same direction, not backwards and forwards. The end of the piece of steel last touched by the permanent magnet will be of opposite polarity to the pole of the magnet which is used to stroke it. Thus supposing (Fig. 61) the bar of steel had one end marked to distinguish it from the other, and that the steel were stroked from the marked end with the south pole of the magnet, then the marked end would become the north pole.

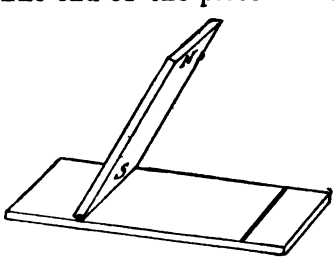


FIG. 61.

Forms of Magnets.— A common form of magnet is that of a horse shoe; and when several magnets are placed with their similar poles together, we have a *compound* magnet; to preserve the magnetic power of such magnets, their ends should be joined by a piece of soft iron, called

the *keeper*. When a weight is suspended from the keeper, the magnetic force of the magnet supports both weight and keeper. A straight bar of steel is also used as a magnet.

Figs. 62 and 63 represent the horse shoe and the compound magnet with their keepers. Fig. 64 is a bar magnet of steel.

FIG. 62.

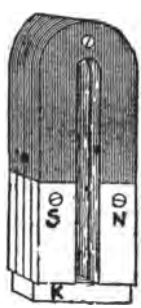


FIG. 63.

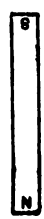


FIG. 64.

Applications.— A very important application of magnetic attraction is the *Compass*, or *Magnetic Needle*, used by mariners and surveyors.

The Mariner's Compass is used for guiding ships during their course of navigation. Its main parts are: A thin flat magnet, commonly called the compass needle, which is mounted and supported horizontally, on a sharp point or pivot. The magnet carries, and is fastened to, a *compass card* in a manner such that the magnet is under the card,

that the center of the one is also the center of the other, and that the north and south points of the compass card are fixed immediately over the north and south poles of the magnet. (Fig. 65.)

Permanent magnets are also used for separating magnetic iron ore from the sand with which it is found. They are frequently used by surgeons to remove particles of steel or iron from the eye, so

FIG. 65.
Mariner's Compass.

situated as to make their extraction with ordinary instruments difficult, if not impossible. To ascertain the presence of steel or iron in any of the tissues, a powerful magnet is held for twenty or thirty minutes on the injured parts. The fragments of imbedded iron or steel become magnetized. Their exact location may then be ascertained by the dip of a delicately suspended needle. Sewing needles, forced into the flesh by accident, have been brought within reach by the persistent action of strong magnets.

The Earth's Magnetism.— The fact, as has been stated, that if a magnet be freely suspended, it will come to rest, so that its poles point towards the poles of the earth, shows that the earth acts as if it contains within it a magnet, some of whose lines of force pass along the surface of the earth. The magnetic poles of the earth are not exactly at the geographical north and south poles. Consequently, the magnetic needle does not at all places on the earth's surface point truly north and south. The direction which a magnetic needle takes is called the Magnetic Meridian. The angle, which the magnetic meridian at any place makes with the great circle which passes through the geographical poles of the earth, is called the Declination of the needle of that place. In Fig. 66, *N. S.* represent the geographical poles, and *n. s.* the magnetic poles. The angle *Non* is called the declination.

47TH EXPERIMENT. — **Suspend by an untwisted thread a small magnetic needle over a bar magnet** *N. S.*, Fig. 67. At the middle of the bar magnet the needle will be horizontal, with its north pole pointing toward the south pole of the magnet. Let the needle approach the north pole of the bar magnet. It will be noticed that the south pole of the needle dips or inclines

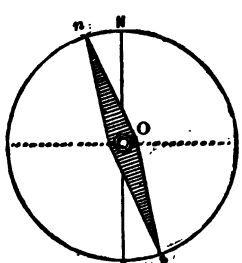


FIG. 66.

toward the north pole of the bar magnet. Now let the needle approach the south pole of the bar magnet. The north pole of the needle will dip towards the south pole of the bar magnet. This dip or inclination increases as the needle approaches the poles, at which point it is 90°.

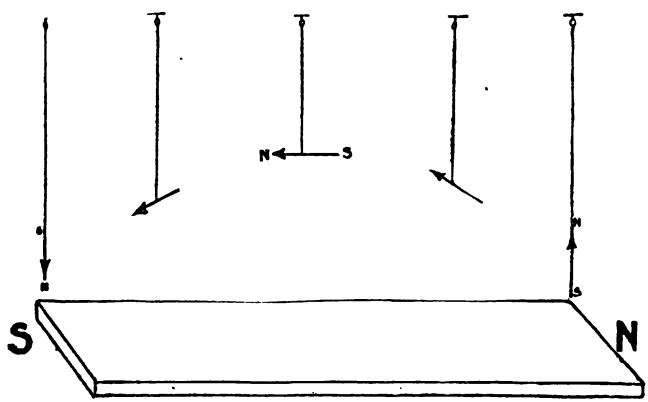


FIG. 67.

If a needle be balanced so as to be horizontal when suspended by a thread, and then be magnetized, it will not only point toward the north, but will also point downward. The angle at which it is inclined to the horizon is called the dip or inclination of the needle, and is due to the fact that the earth is round. In the Northern hemisphere the north pole dips down; in the Southern hemisphere, the south pole. (Fig. 68.)

The declination and dip of the magnetic needle varies periodically, yearly and daily. These changes are regular; others, which are irregular, are called

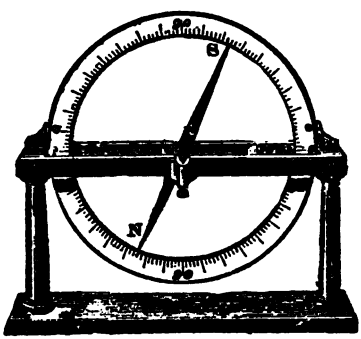


FIG. 68.

magnetic storms. These accidental variations are chiefly due to earthquakes, the aurora borealis and volcanic eruptions.

PART VI. — STATICAL ELECTRICITY.

LESSON XXXVII.

ELECTRIC ATTRACTION.

48TH EXPERIMENT.— **Rub a bar of sealing wax, or a strip of hard rubber (or a rubber comb) with a piece of flannel; or a heated glass rod with a piece of silk. Then hold the subject rubbed, as the piece of hard rubber, to some minute light bodies, such as feathers or finely cut tissue paper. At the instant that the rubber is withdrawn, some of these minute**

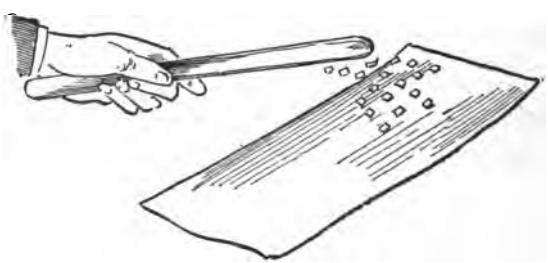


FIG. 69.

bodies will be seen to adhere to the rubber. The rubber has evidently acquired the power of attracting those little bodies. An empty egg-shell may be made to roll after the excited rubber. (Fig. 69.)

49TH EXPERIMENT.— **Heat a piece of paper over a stove or lamp, place it quickly upon a**

table, rub it with a piece of India-rubber, and then bring it near some such light bodies as mentioned above; it will attract them.

Electric attraction is attraction which certain bodies manifest after being rubbed.

50TH EXPERIMENT.— **If in a warm room**, with a dry atmosphere, we bring the knuckle near electrified sulphur, glass or paper, we may see a spark pass from the substance to the hand, and be able to light the gas, if we present the knuckle to an open gas burner. At the same time we may hear a cracking noise, feel a slight stinging in the hand, and perhaps notice a peculiar odor.

Familiar Facts.— **The fur of a cat** when rubbed with the hand, a gutta-percha comb passed through the hair, or the strong friction of India-rubber bands against rapidly moving axles or wheels, will produce electric currents more or less perceptible according to circumstances. If an electrified body be held close to the face, a peculiar sensation is felt, as though the face were being covered with a cobweb; this is on account of the attraction between the electric object and the fine hair on the face, which causes the hair to move.

But what has become of the electricity that passed from the sulphur or glass, to the knuckle? If it had

remained there, the knuckle would certainly attract light bodies; but this is not the case. Neither the knuckle nor the hand is now electrified. The electricity spread all over the body and passed to the earth, and was sensibly lost. So if we bring a key near electrified sulphur or glass, the electric current will pass over to the key, and will not stay there; it passes into the hand, and thence through the body to the ground.

Metals and the human body are conductors of electricity.

51ST EXPERIMENT.— **Instead of the** hand or key, take sealing wax, silk, glass, India rubber. These objects act quite differently. They will remain electrified after contact. No spark will be seen. Hence *sealing wax, silk, glass and rubber are non-conductors of electricity.* If any part of a *non-conductor* of electricity is electrified, the electricity confines itself to the part that has been electrified; but if any part of a *conductor* is electrified, the electricity spreads itself instantly over the whole surface.

Insulation. — "If you stand upon a board, which is placed upon four warm tumblers, and then present your knuckle to an open gas-burner and let some person strike you with a fox's brush or some other fur, you will be able to light the gas. If you hold

the knuckle near to the person a spark will pass from you to him. The attractive force may be increased if you throw a rubber coat over you and then receive the stroke with a fox's brush. The board rests on the tumblers for the purpose of *insulating* the person standing upon it. For glass, rubber, and silk are insulating substances." (Tyndall's Lessons on Electricity.)

Hence these substances are frequently used to cover the handles of electrical machines and apparatus, to prevent the electricity from leaking away.

Historical.— The sparks obtained by the rubbing of furs, and lightning, with its companion, thunder, must have been observed by the earliest people upon the earth. Although the Greeks, about 600 years before the Christian era, recorded the attracting property of amber, it was not before the beginning of the 17th century, that a book was published by Dr. Gilbert, an Englishman, who mentions many other substances, such as glass and sulphur, as having the same property. This author stated correctly that *magnetism attracted as well as repelled*, but, curiously enough, he added that electricity only attracted.

In 1670, the first electric machine was constructed by Otto Guericke, burgomaster of Magdeburg, the inventor of the air-pump. He also discovered the

property of electric repulsion; and later on excited electricity by means of sulphur (brimstone) exposed to friction.

The distinction between *conductors* and *non-conductors* of electricity was discovered by Mr. Stephen Grey. He wished to electrify a cord suspended by linen threads, but was unsuccessful because the electricity, when entering the cord, at once passed over to the threads. The threads thus were found to be conductors of electricity. Upon the suggestion of a friend he tried silken threads; as silk is a non-conductor, the experiment then was successful.

LESSON XXXVIII.

ELECTRIC ATTRACTION AND REPULSION.

52ND EXPERIMENT.— **Suspend a pith ball attached** to a silk thread, from the hand or some other support (Fig. 70). On presenting it to an

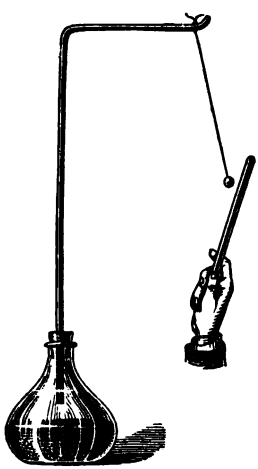


FIG. 70.
Attraction.

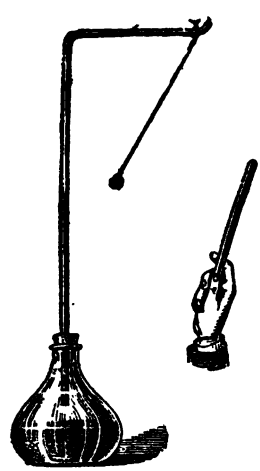


FIG. 71.
Repulsion.

electrified bar of sealing wax, it will be seen that the ball is attracted by the sealing wax; that it comes in contact with the same; and that, after it has become electrified itself, it is *repelled*. If we then

slowly follow it with the sealing wax, it is repelled still farther. The repulsion between the two bodies continues, until the aqueous vapor in the room, or some other good conductor, deprives the ball of its electricity.

53RD EXPERIMENT. — **Suspend two pith balls** each from a silk thread. On presenting electrified sealing wax, they become electrified themselves by contact with it, and then repel each other. They no longer hang vertically; for the attracting and repelling force of electricity may overcome gravity. We know from Lesson XXXVI that magnetic force may overcome gravity.

54TH EXPERIMENT.— **Repeat the 52nd Experiment** with a single pith ball; after it becomes electric, present to it an electrified glass rod or tube. Immediately the ball will be attracted by the electricity of the glass.

55TH EXPERIMENT.— **Repeat the 53rd Experiment,** and after the two balls are separated by repulsion, present electrified glass to one of them. The glass will attract this ball and impart its electricity to it; after which the ball will be repelled from the glass and at once fly to the other ball.

When the two balls had the same kind of electricity they *repelled* each other; now that they

possess different electricity — the one glass electricity, the other sealing wax or resinous electricity — they *attract* each other.

56TH EXPERIMENT.— **Bring electrified sealing wax, or hard rubber,** near one of the two balls, electrified glass near the other. The balls will at first be attracted and then repelled, when they will fly toward each other and stay together. This is easily understood if we remember that one ball had glass electricity, and the other sealing wax, or, *resinous* electricity. It appears then that there are two kinds of electricity, viz.: *Vitreous* or *Glass Electricity*, generally called *Positive Electricity;* and *Resinous Electricity*, generally called *Negative Electricity*.

The substances named in the following list are in such order that if any two of them are rubbed together, the first will be positively electrified and the second negatively electrified:—

1. Cat's skin.	4. Cotton.	7. Iron.
2. Flannel.	5. Silk.	8. Resin.
3. Glass.	6. Wood.	9. Gutta-percha.

Like electricities repel each other; unlike electricities attract each other.

Suppose a cloud happens to contain positive electricity; it will call forth negative electricity either

from some cloud near by, or from the atmosphere or from the earth. And were its electricity negative, it would call forth positive electricity. When two clouds, or a cloud and the earth, are sufficiently near to each other, their electricities unite. When uniting, one of them leaps over the space between them. This passage of electricity through the air often produces great electric sparks which are called *Lightning*.

Familiar Facts.— **Electric currents may pass** from one cloud to another, from the clouds to the earth, or also from the earth upward to the clouds. It sometimes happens that lightning *strikes* — that is, strikes objects on the earth. *Tall* objects made of *good conducting material* are most liable to be struck, inasmuch as they more than any other class of bodies attract the electricity of the atmosphere or clouds. High houses, tall steeples, trees or chimneys, offer a good passage to electricity. In its onward course, the current prefers the best conductors; it passes along the spouting of houses, along water-pipes, stove-pipes and iron pillars. It heats metallic objects, and if they are small, may melt them; it splits trees into fragments, and kills living beings by destroying the activity of their nerves.

The safest place during a thunder-storm is the portion of a room not too near the fire-place, stove,

chandelier, gas-pipe or bell-rope. Why is it unsafe to seek shelter under tall trees, or in the entrance of a house with rain pouring down over it?

Knowing that electric currents follow the best conductors, Franklin invented the *Lightning Rod*, as a means of directing them into the ground. It consists of a copper rod with a metallic point, which protrudes several feet above the roof, in order that on the approach of a current the metallic point, and not the building, shall be struck. The rod conducts the electric current into the earth where it can do no harm. But the connection between the point and the earth must be perfect; that is, the rod must be put in direct contact with the wall, else the electric current may pass over to the building.

The purpose of lightning rods appears to be: 1st, to attract electric currents; and 2d, to conduct them safely into the ground.

LESSON XXXIX.

METHODS OF ELECTRIFICATION — CONTACT — INDUCTION — ELECTRICAL MACHINES.

The attractions and repulsions of electrified bodies are studied by means of the *electroscope*. It is also used for the purpose of indicating the presence of an electric charge, and of ascertaining whether it be positive or negative. It consists of a metal rod, which passes through a rubber stopper in a glass flask or receiver. Attached to the lower end of the rod are two small gold leaves, which hang side by side. Soldered to the upper end of the rod, which projects into the open air, is a metal plate or ball. (Fig. 72.)

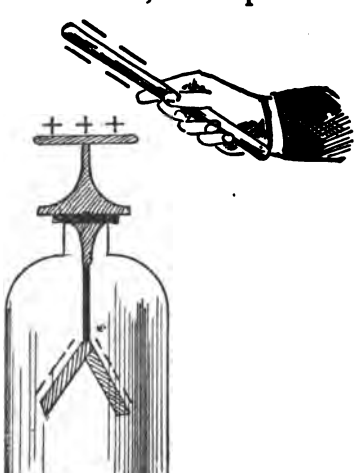


FIG. 72.

57TH EXPERIMENT — *Electrification by Contact.* — **Rub a gutta-percha ruler** with flannel. The ruler will be negatively electrified (see table shown in Lesson

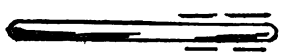
XXXVIII.). Bring it in contact with the plate of the electroscope for a second and then remove it. The leaves, which before hung vertically, will now diverge or repel each other.

The leaves of the electroscope will be negatively electrified.

58TH EXPERIMENT.— **Now touch the plate** with the finger, the leaves immediately collapse into their former position.

From Experiment 57 and Experiment 58 we learn *that bodies may be charged by contact with an electrified body; and discharged by contact with an unelectrified body.*

59TH EXPERIMENT— *Electrification by Induction.* — **Bring the electrified ruler** near the plate of the electroscope. Touch the plate for an instant; remove the hand and then the electrified rod. The leaves repel each other (Fig. 73). They will be *positively* charged by *induction.*



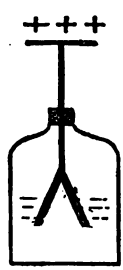


FIG. 73.

Explanation.

When the negatively charged ruler is held

near the plate of the electroscope, the *positive* electricity, on the plate and leaves, is attracted to the upper surface of the plate and the *negative* electricity is repelled into the leaves which diverge. It must be assumed that when a body is unelectrified that the positive and negative electricity neutralize or balance each other. It follows, from this assumption, that every unelectrified body contains both positive and negative electricity, in equal quantities. When this equilibrium, as it were, of the two kinds of electricity is destroyed, we say a body is electrified. So that, when the ruler is brought near the electroscope, the two kinds of electricity on the plate and leaves will simply be rearranged. Nothing has been added nor taken away. But when the plate is momentarily touched with the finger, the electricity, which is in the leaves, and which is always of the same sign as the inducing rod, escapes through the body to the earth, leaving an excess of positive electricity. The plus charge on the plate is not affected by the touch of the finger, because it is *bound* or *held* by the opposite charge on the rod.

Hence, *when a body is charged by induction the charge it receives is opposite in kind to that of the inducing body.*

60TH EXPERIMENT.— **Bring a negatively** charged rod, a vulcanite ruler rubbed with flannel, near the

electroscope, which is still charged positively as a result of Experiment 59. Note that the leaves gradually approach each other. Now remove the rod and they will return to their former position.

61ST EXPERIMENT. — **Repeat this operation,** using a glass rod rubbed with silk (a glass rod rubbed with silk will be positively electrified). Note that in this case the leaves are more and more strongly repelled as the rod moves toward the plate, and that they return to their former position when the glass is withdrawn.

Hence, *when a negatively charged body is brought near a +ly electrified electroscope*, the leaves will converge or come together. When a positively electrified body is brought near a positively electrified electroscope the leaves will diverge or open out.

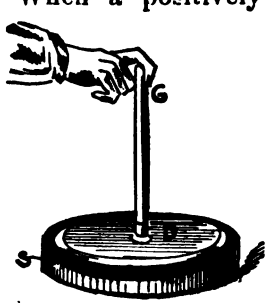


FIG. 74.

The Electrophorus. — The simplest form of machine for electrifying by induction is the electrophorus. This consists of a disc of solid metal (D) which rests upon a plate of vulcanite or sealing wax (S). At the middle of the metal disc is attached a glass handle (G). (Fig. 74.)

Owing to the irregularity in the surface of the disc and of the plate upon which it rests, contact is made only at a few points, the remainder of the disc being separated from the bed of sealing wax by a thin film of air. An electrophorus can be very easily made by pouring sealing wax into a pie plate, making the surface of the wax as level as possible. To the center of another smaller pie plate fasten a handle of glass.

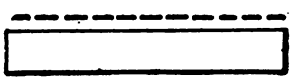


FIG. 75.

62ND EXPERIMENT. — **Stroke the sealing wax** with a warm piece of flannel so as to electrify it negatively. Place the disc upon the wax. Touch the disc with the forefinger and then remove it from the

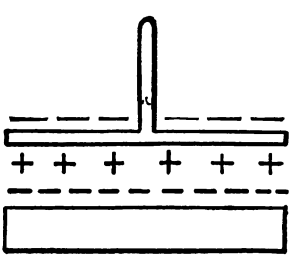


FIG. 76.

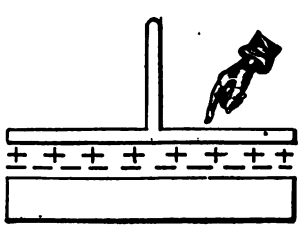


FIG. 77.

sealing wax. It will be found sufficiently charged with positive electricity to yield a spark when the knuckles of the hand are presented.

63RD EXPERIMENT.— **Touch a gas pipe** with the electrified disc, it will ignite the gas.

64TH EXPERIMENT.—**Bring the point of a sewing needle held in the hand near the disc. Quite a shock will be felt.**

Explanation.

When the sealing wax is rubbed with flannel or cat's skin its surface becomes negatively electrified (Fig. 75). When the disc is placed upon the

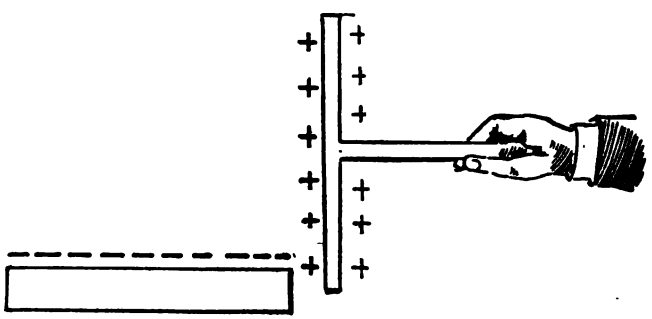
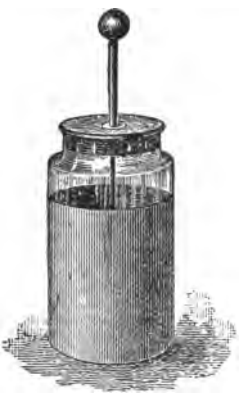


FIG. 78.

sealing wax, it rests upon three or four points only. The negative electricity of the sealing wax acts inductively upon the disc above, attracting a positive charge to its under side and repelling a negative charge to its upper surface (Fig. 76). When the finger touches the disc, the negative electricity is repelled through the body to the earth (Fig. 77), leaving the positive charge which is bound on the under surface. If now the disc is raised the positive charge is no longer bound and will distribute itself on both sides of the disc (Fig. 78).

The Leyden Jar consists of a glass jar, coated inside and outside with tin foil. This tin foil does not quite reach the top. The remainder of the glass, inside and out, is coated with shellac varnish. A wooden top is provided, which supports a brass rod, terminating at its upper extremity in a ball, and its lower in a short piece of chain which serves to connect the rod and ball with the inner coating (Fig. 79).



The Leyden Jar.
FIG. 79.

This jar is used for storing electricity in what is called its static form, and will hold a charge a long time. It is also called an electrical condenser. Such a charged jar may be discharged by connecting the inner and outer surface by any conductor. The knob *alone* or the outer surface alone may be

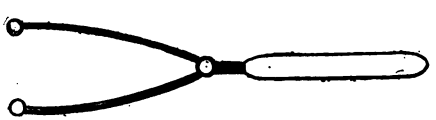


FIG. 80.

held in the hand with safety. It is entirely safe to hold it in the hand while charging it. In discharging it a device which consists of two metallic arms with a glass handle is used (Fig. 80). To charge the

jar, hold it in one hand and bring the knob in contact with the terminal of a Holtz machine or other charged body.

The Toepler Holtz Machine is a device for generating and collecting large quantities of statical electricity by induction (Fig. 81). It consists of

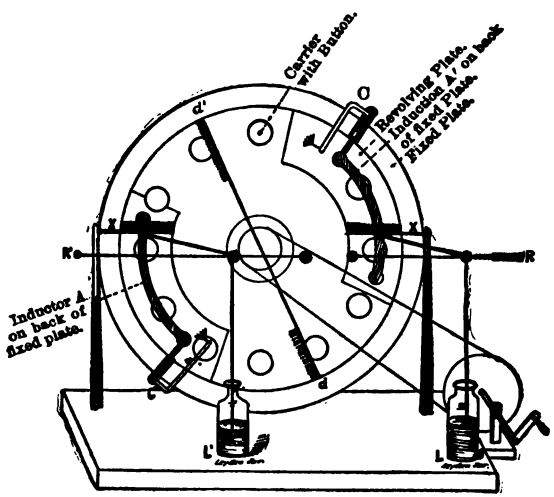


FIG. 81.

two vertical glass discs, one of which revolves while the other is stationary. The revolving plate is called the front, and the fixed plate the back of the machine. On the back of the fixed plate are two pieces of varnished paper, *A A'* (Fig. 82), called the inductors. Upon the revolving glass plate are pasted tin foil *carriers*,

having a flat metal button on the center of each (Fig. 83). Let the inductor A have a small positive charge. One of the carriers c on the revolving plate will be opposite the point a of the inductor A. The positive charge on A will act inductively across the glass repelling positive electricity to the button, and attracting negative electricity on the tin foil around the button. The button, in its revolution, then comes in

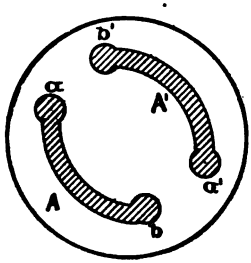


FIG. 82.

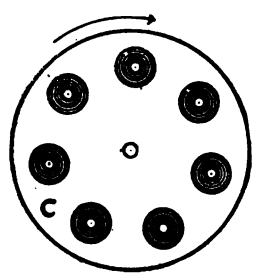


FIG. 83.

contact with a tinsel brush upon the end of the rod $d\ d'$ (Fig. 81) and the repelled charge (positive) is neutralized by a minus charge which is repelled from a diametrically opposite carrier. The carrier thus charged negatively by induction is carried by the revolution of the plate to a point opposite b' upon the negatively charged inductor $A.'$ Here it passes under another brush C with which it shares some of its charge. This brush is connected, by means of a bent metallic arm, with the inductor A' on the back of the fixed plate. Finally the carrier

c passes under the collecting comb X and delivers another portion of its charge to the Leyden jar L, which is connected by means of metallic rods to the comb X.

In the meantime the carrier diametrically opposite to the carrier c, is undergoing a similar operation, but with an opposite charge, whereby the Leyden jar L' is stored with positive electricity.

When the revolving plate is turned, there is a continued accumulation of positive and negative electricity, respectively in the two Leyden jars L and L'. If now the sliding rods R and R' are set so that the balls with which they are tipped are a few inches apart, the attraction between the charges becomes so great as to overcome the resistance of the intervening air, whereupon a spark leaps between them.

PART VII. — CURRENT ELECTRICITY.

LESSON XL.

CHEMICAL ELECTRICITY.

65TH EXPERIMENT. — Take a piece of sheet zinc of about the size of half this page; also a piece of sheet lead of the same size and put between them a piece of flannel or blotting paper a little larger than the two metals. Then lay the three pieces upon a china dish; a few feet of small and flexible copper wire is then fastened to the zinc near the edge, and the whole may then be covered with a dilute solution of blue vitriol. This solution is readily obtained by dissolving a

FIG. 84. — ELECTRIC CELL.

small quantity of blue vitriol (sulphate of copper) in water. The lead being below in the dish, next comes a cloth or paper; the zinc is on top of the cloth, and all three are covered by the solution. Such an arrangement may be called an Electric Cell or Galvanic Cell. Two or more Electric Cells are called an Electric (or Galvanic) Battery. Another simple cell may be fitted up by means of a strip of zinc and a piece of carbon, both suspended in a jar,

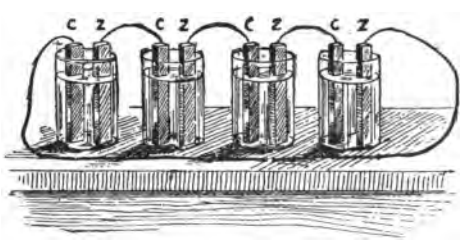


FIG. 85.

filled with a solution of bichromate of potash mixed with a little sulphuric acid. The zinc must not be in contact with the carbon. There are a variety of Electric Cells in the market, any of which may be purchased for a small price and will be found serviceable for our experiments.

The contact of two different metals (or of zinc and carbon), placed in a certain liquid, produces Chemical Electricity.

Arrangement of Cells in Battery. — Whenever an electric cell is not strong enough for the purpose desired, a number of cells may be arranged in such a manner that they will act together. If a current is to be sent through a long thin wire the cells are so arranged that the zinc of one is connected with the carbon or copper of the next. In Fig. 85 four cells are so connected.

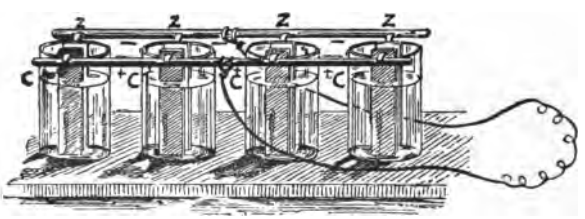


FIG. 86.

This is called arranging cells in *series*. If it is desired to send the current through a short thick wire the cells are so arranged that the zinc plates are all electrically connected with one another, and the carbon plates are similarly connected. Fig. 86 shows this arrangement. Such cells are said to be connected *in multiple* or *in parallel circuit*.

LESSON XLI.

ELECTRICAL UNITS.

The Ohm.— When electricity flows through any medium it meets with resistance. The amount of resistance offered depends upon the nature of the material through which it flows, its length and cross section. The unit resistance, called the *Ohm*, is the resistance of a column of pure mercury having a section of one square millimetre and length of 106.28 centimetres at a temperature of 0° C. A copper wire having this section and about 300 feet long offers a resistance of one ohm.

The Ampere.— The magnitude of the effect produced by an electric current depends, among other things, upon the *strength of the current.*

By current strength is meant the number of units of electricity which flows in a given time, or, briefly, it is the rate of flow. If a current is passed through a solution of blue vitriol (copper sulphate), it will decompose the solution and deposit the copper. The current strength is measured by the amount of copper it will deposit in a second or an hour.

An ampere is the amount of current capable of depositing 1.17 grams of copper per hour.

The Volt.— In order to drive a current through a conductor there must be a difference of potential between its ends. This difference is called electro-motive force or electrical pressure.

The unit of electro-motive force is called the *volt*. It is the pressure required to maintain a current of one *ampere* through a *resistance* of an ohm.

LESSON XLII.

ELECTRO-MAGNET — ELECTRO-MAGNETIC TELEGRAPH — ELECTRIC BELL.

66TH EXPERIMENT.— **Take a short iron rod** or an open jack-knife and wind the copper wire around it, as in Fig. 84, and attach the free end of the wire (which should first be scraped clean) to one of the metals of the cell. Care must be taken that no portions of the wire touch each other, and that the points where the wire is attached to the two metals are kept free from the solution. The electric current which is generated at the zinc, runs from the zinc through the liquid to the other metal, and thence through the air along the wire back to the zinc.

If now iron filings are brought to the ends of the rod or jack-knife lying within the wire spiral, we find that they are attracted by the iron; but when the current is *broken*, which takes place when the wire is disconnected from either of the metals in the cell, the filings will drop. (A very small portion of the filings sometimes still adhere after the wire is broken, but this is owing to impurities in the iron rod.) The iron "core," as it is often called, becomes a magnet while the electric current

travels around it, but loses its magnetism instantly when the current, or the "circuit," is broken.

If a magnetic needle be brought near the iron rod or jack-knife while the circuit is closed, the needle will indicate attraction or repulsion according to the end of the rod to which it is nearest. This is further proof that while the circuit is closed, the *core* within acts like a magnet.

The term "current" does not mean that an actual stream or current flows through the wire when the circuit is closed. The term is used for want of a better word; it implies a certain power derived from the cell or battery, and communicated along the wire.

Soft iron is magnetic when an electric current passes around it; it ceases to be magnetic when the current is interrupted or broken.

A piece of soft iron, which is made into a temporary magnet while an electric current flows around it, is called an *Electro-Magnet.*

The usual form of the electro-magnet consists of two iron cores, connected at the bottom or top by a piece of iron called the yoke. Around these cores a great many turns of wire are wound, called the coils. The coils in the cores are so wound that if

the cores were straightened so as to form one core the coils would be a continuation of each other. Then one end of the core becomes the north pole and the other end the south pole. In Fig. 87 *A* and *B* are the coils, *C* and C^1 the cores, and *Y* is the yoke.

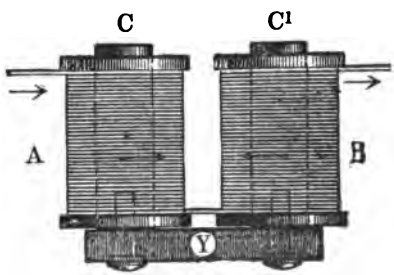


FIG. 87.

Electro-magnets are preferable to permanent magnets because their magnetism is controllable and much more powerful. Hence the great usefulness of the electro-magnet in its application to electric bells and telegraphic instruments.

The Electric Telegraph. — The most essential part of an electric telegraph is an electro-magnet, which in its simplest form consists of two short iron "cores" or "spools" placed near, and parallel, to each other, as in Fig. 88. Insulated copper wire is wound first round one of them, and then round the other; the ends of the wire are each attached to one of the metals of the electric cell. When this is done, the current is closed, that is, it flows from one of the metals of the cell, or battery, through the fluid to the other metal, and thence along the wire, in the air, and along the wire of the electro-magnet back

to the first metal in the cell. While the current is thus passing through the coils, the soft iron within each coil is converted into a magnet; consequently a small piece of iron near the poles of the "cores," called the *keeper*, *a* (Fig. 88), is attached and drawn

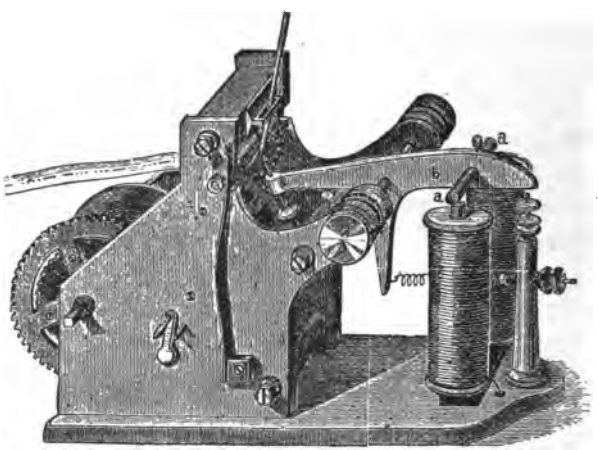


FIG. 88.

toward them. The keeper is fastened to one end of a short lever, *b*, at the other end of which is a small "style" or pencil, with a point turned upward. As said before, when the circuit is closed, the keeper is drawn against the electro-magnets, which causes the little pencil to be pressed upward against a strip of paper, which is propelled past the pencil by

means of clockwork. When the circuit is opened, the "spools" cease to be magnetic, the keeper is no longer attracted to them, and the pencil-end of the lever therefore falls away from the paper.

With the aid of a simple apparatus called a *key*, Fig. 89 the circuit may be closed and opened by the operator at his will. It matters not that he

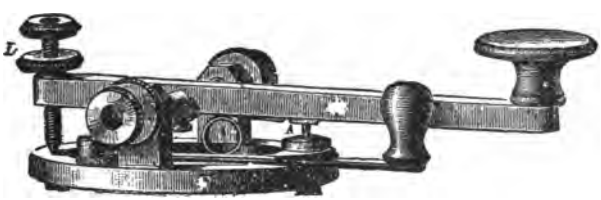


FIG. 89.

may be hundreds of miles away from the receiving station, where, in obedience to his pressure on the key, the little pencil in striking against the endless paper strip, records a series of letters which are made up of lines and dots, according to a system contrived by S. F. B. Morse. It is as follows:—

A – —	J — – — –	S – – –	1 – — — –
B — – – –	K — – —	T —	2 – – — – –
C – – –	L — – –	U – – —	3 – – – — –
D — – –	M — —	V – – – —	4 – – – – —
E –	N — –	W – — — —	5 — — — —
F – — –	O — —	X – — – –	6 – – – – –
G — — – –	P – – – – –	Y – – – –	7 — — – –
H – – – –	Q – – — –	Z – – – –	8 — – – –
I – –	R – – –	& – – – –	9 — – – —
			0 — — —

Between successive letters operators leave a small space; between words a longer space, and a still longer one between sentences. Most operators become so experienced from long practice that they understand and are able to write down a message from hearing the sounds made by the clicks of the lever, without using the paper or any other recording apparatus.

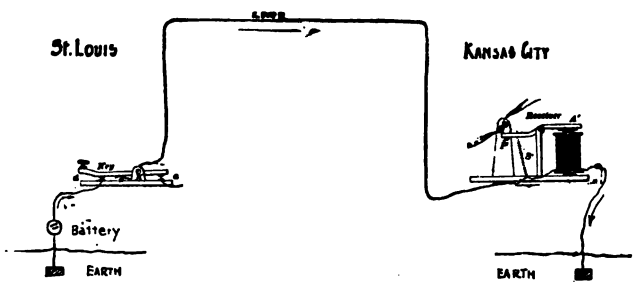


FIG. 90.
Electric Telegraph Circuit.

The principles of the Electric Telegraph, then, are three in number, viz.:—

I. An electric current flowing round an iron core converts the iron into a temporary magnet.

II. The circuit may be opened and closed at the will of the operator.

III. The sending station may be hundreds of miles distant from the receiving station.

Submarine Cables.— Submarine and underground circuits are protected by means of sheaths of gutta-percha or India-rubber covering. Fig. 91 shows a cross-section, and Fig. 92 a projection of the Anglo-American Atlantic cable, drawn full size. The center is formed by a copper strand of seven wires; round this is a gutta-percha envelope, covered by a serving of jute; on the outside of this there are ten iron wires; each enveloped in fine strands of Manilla hemp.

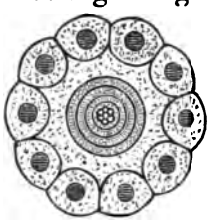


FIG. 91.

FIG. 92.

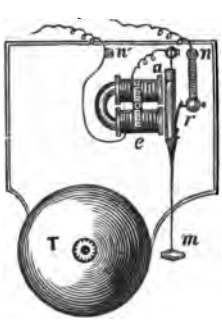


FIG. 93.

Electric Bells. — For household, office or similar purposes, the most convenient form of electric bells used is represented by Figure 93. It is sometimes called a *Trembler*. The electric current enters at *n* or *n'* whenever the circuit is closed. This is done by the smallest pressure on a little button or knob.

After entering at *n'* and passing through the electro-magnet at *e* and running through *a r*, which is a keeper and at the same time the lower part of a hammer, *a r* is attracted to the electro-magnet which causes the head of the hammer *m* to strike a blow. At this instant the circuit is broken at *r*, which causes the hammer to spring back to its original place, but at this moment is closed again and the action is repeated as before, so long as a current is sent along the wire; that is, so long as the little button is depressed.

LESSON XLIII.

LIGHTING AND HEATING EFFECT OF ELECTRICITY — ELECTRO-MAGNETIC INDUCTION.

Electric Light.— If an iron file be attached to one of the wire-ends or *poles* of a cell or battery,

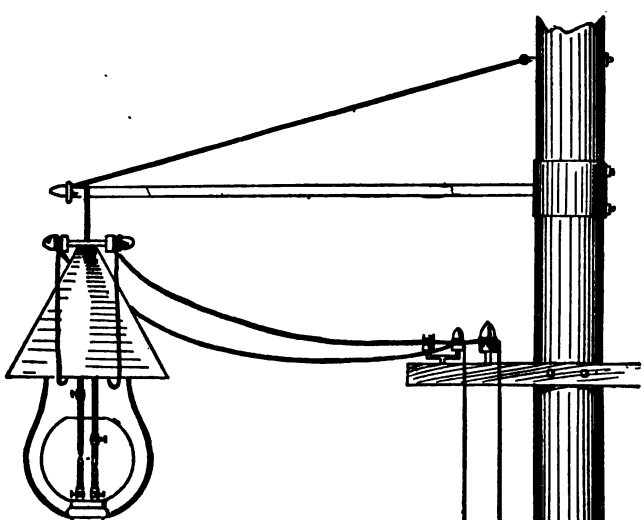


FIG. 94.

and we pass over it with the other wire-end, a rapid succession of bright sparks is observed, which is caused by the burning-up of minute particles of

iron. If one of the wires be connected with mercury, and the other be then dipped into the mercury, a single intense white spark will be produced on the mercury at the instant of contact.

If thick wires are connected with the poles of a galvanic battery, with a pointed carbon rod attached to the end of each wire, then if the points of the rods are placed nearly in contact with each other (the distance between them being exceedingly small), the carbon points will yield each an intense white light, while the space between them is occupied by an "arc" of light. The carbon rods are especially prepared for the purpose, so as to be good conductors of electricity. (Fig. 94.)

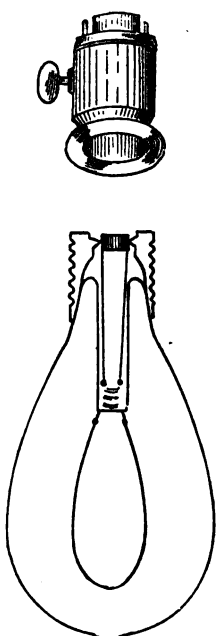


FIG. 95.

Most modern electric lights are generated by means of huge electro-motor machines driven by steam.

Incandescent Light. — When a current is sent through some substance that offers a high resistance, it becomes intensely heated and brilliantly incandescent. A suitable substance for this purpose is carbonized

bamboo, which is inclosed in a glass bulb from which all the air has been exhausted to prevent combustion. (Fig. 95.)

Heating.— Electricity is now also used in cooking and ironing. The heat is produced by passing a

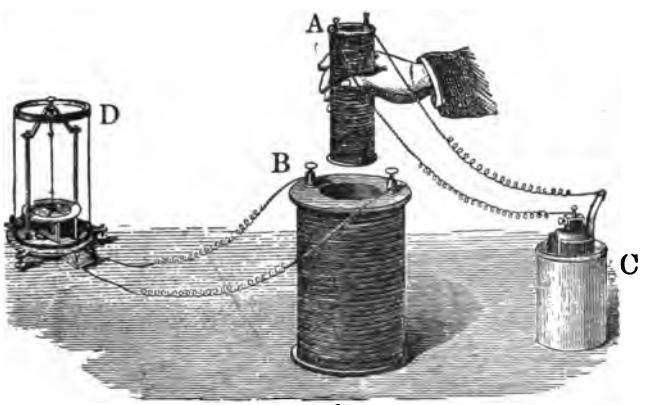


FIG. 96.

strong current of electricity through a conductor which offers a high resistance to the passage of the current.

Electro-Magnetic Induction.

We have seen that a charge of electricity has the power to induce another charge in a body near it. This is called *electrostatic induction*. In the case of current electricity we also find that, when a magnet or an electro-magnet is moved near a closed wire, a current of electricity is induced in the wire. *This is called electro-magnetic induction.*

67TH EXPERIMENT.— Let *A* (Fig. 96), represent a coil of wire which forms a closed circuit with the battery *C*. Let *B* represent a larger coil of wire, which is connected with a galvanometer *D* (a pocket compass surrounded by a few turns of wire will answer the same purpose). A galvanometer is an instrument which will detect a current, its direction, and show whether it is weaker or stronger than another current. If, when a current is flowing through *A*, it be thrust into the coil *B*, a current will be induced in *B* and will be shown by the deflection of the magnetic needle in the galvanometer or pocket compass.

Suddenly remove *A*, a current will be set up in an opposite direction as shown by the needle. The first coil is called the *primary* and the other the *secondary* coil.

Induction Coils.— The foregoing experiment indicates the principle upon which the induction coil is constructed. This consists of an iron core *c* (Fig. 97), surrounded by a coil of wire *p*. This is called the *primary* coil. This in turn is surrounded by another coil *s*, called the *secondary* coil. The ends of the wire forming the secondary coil are connected with two binding posts *t t'* which are usually made to contain two rods *R R'* free to slide, so that the length of the spark may be increased or diminished.

In order to break the circuit through the primary coil a device called a contact-breaker is used. It consists of a fine spring, *a*, carrying an iron armature. This spring is attached so as to keep the armature away from the core, *c*, of the induction coil, and so arranged that it will make contact with a screw, *T*, which forms part of the battery circuit. When the current is turned on, it flows

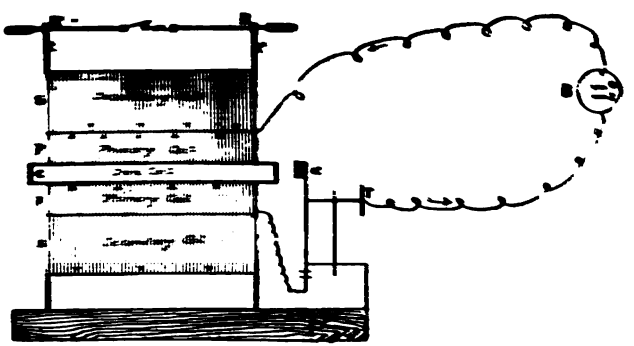


Fig 97.

through the *primary* into the spring *a*, and then through the screw *T* back to the battery *B*. The core of the primary coil, being of soft iron, becomes magnetized and draws the armature *a* away from the screw *T*. This breaks the current at that point and shuts it off from the primary. The core being no longer a magnet, the spring flies back to its original position and the circuit is again closed. This process goes on so long as the current is

allowed to flow, thus effecting a continuous vibration of incredible rapidity. At each vibration of the armature a spark leaps across between the balls on the rods R and R'. Fig. 98 shows the usual form of the induction coil.

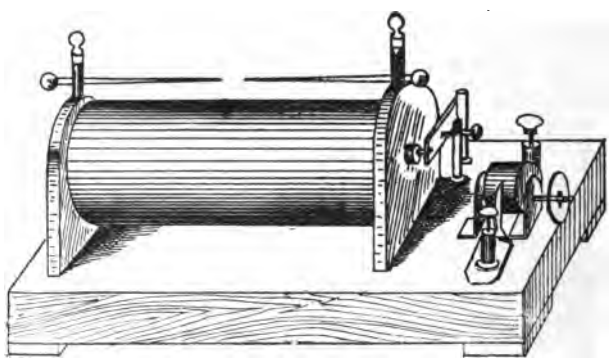


FIG. 98.

The Telephone is an instrument which utilizes the application of electro-magnetic induction for the reproduction of speech.

Bell's Telephone (sound afar) consists of a magnet $N\,S$, Fig. 99, around one end of which is wound a coil of fine wire, C. Near this end is a thin iron plate, T, and a mouth-piece, M. The ends of the coil are carried to the binding posts, d, d, which connect them, one with the earth, the other with a line wire.

One telephone is at the sending station, the other at the receiving station; both are connected with each other by wire, so that the distance between the two stations may be 100 miles or more. The vibrations of a voice at *M* strike plate *T*, and cause it to vibrate. As the vibrating plate approaches *N*, an electric current is induced in coil *C*, and thence carried along the line wire. As the vibrating plate recedes from *N*, the current ceases, but the currents which are transmitted to the line wire, produce vibrations in the iron plate of the instrument of the receiving station which are like the original vibrations caused by the voice at the sending station, and

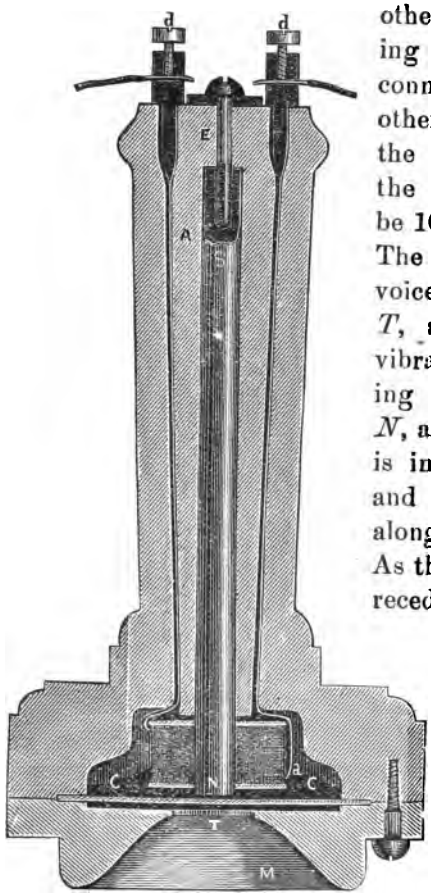


FIG. 99.

may be heard by a person at the receiving station holding the telephone to his ear.

Dynamo-Electric Machine.— The most important application of electro-magnetic induction is the dynamo and motor.

The dynamo is simply a coil or series of coils of wire, known as the *armature*, revolving between the poles of a powerful electro-magnet, called the *field magnet.*

Fig. 100 represents the principle of a simple series wound dynamo. Two large bars of soft iron C and C', surrounded by a coil of insulated wire, terminating in the poles N S. Between these two poles the armature A is made to revolve by means of a steam engine. The rapid revolution of the armature between the poles produces a current in the armature, which is conducted off by springs a and b, called brushes. The current, it will be noticed, first passes through the field magnet in order to strengthen it, and then into the main circuit.

The Electric Motor.— This in structure is simply a dynamo. We have seen that when the armature of the dynamo is revolved, a current is produced. If this action is reversed and a current from some other source be sent through the armature, it will revolve and may be made to do work.

In a *dynamo* the armature is made to revolve by an engine.

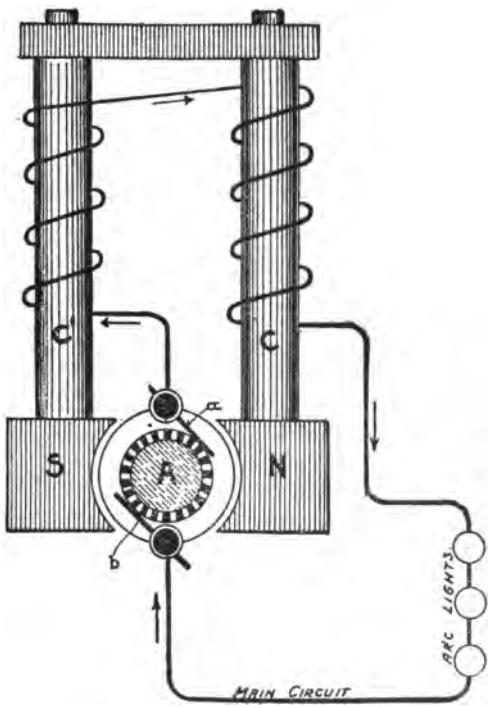


FIG. 100.

In a *motor* a current from a battery or another dynamo is sent through the armature, which causes it to revolve. The same machine may be used either as a dynamo or a motor. But for practical purposes, motors are made slightly different from dynamos. (Fig. 101.)

Electric Street Cars. — The electric current is used in the propulsion of vehicles, such as street railroad cars. At present there are two systems mainly in use, viz. : —

The Storage Battery or Accumulator System, according to which a car carries a storage-battery which generates the current. The current imparts

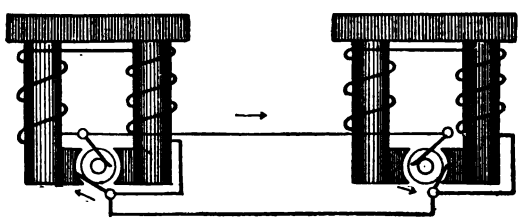


FIG. 101.

motion to a motor connected with the wheels. The main objection to this system is the great weight of the battery. And

The Trolley System, according to which the current passes to the motor in the car along a circuit formed by an overhead wire and the track, the current being generated not in the car, but in a "power-house." From the overhead wire the current passes along a trolley to the car; the trolley is held in contact with the wire by means of a small wheel, the "trolley-wheel." The disadvantage of this system lies in the great loss in transmitting the current along the wire and rails.

LESSON XLIV.

CHEMICAL EFFECTS OF ELECTRICITY.

Electro-plating — 68TH EXPERIMENT. — **Arrange an apparatus** as shown in Fig. 102. *B* is a battery of cells. *C* is a glass beaker, containing a saturated solution of blue vitriol. Fasten a silver spoon *S* to the copper wire attached to the zinc or negative plate

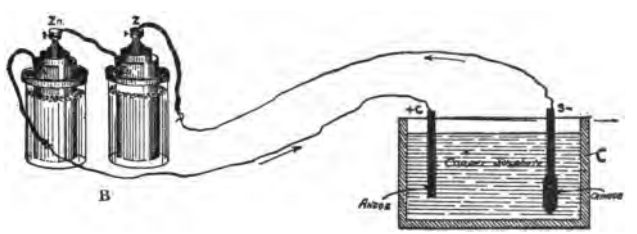


FIG. 102.

of the battery *B* and a piece of sheet copper *c* to the wire connected with the copper plate or positive plate of the battery. Suspend the two pieces of metal in the beaker containing the copper sulphate. Close the circuit, and notice that a firm, hard copper coating is deposited on the silver.

This process is called *electro-plating*. The plates used for the decomposition of substances are called electrodes. The one attached to the zinc wire is

called the negative electrode or *cathode*, and the other is the *anode*.

69TH EXPERIMENT.— **Substitute a solution of the cyanide of gold for the copper sulphate in the above experiment. Gold will be deposited on the silver spoon.**

For plating with silver a solution of the cyanide of silver is generally used.

LESSON XLV.

X-RAYS.

This class of phenomena is developed by electric discharges through rarified gases. When a highly exhausted Crookes tube is connected to the terminals of an induction coil, a faint glow appears between the terminals of the tube. The discharge, which emanates from the terminal, which is connected with the negative pole of the induction coil and called the cathode, proceeds in straight lines through the tube. Wherever this discharge from the cathode strikes the glass it produces a greenish phosphorescence on the inner surface of the glass and on its outer surface *invisible rays* which are known as Roentgen rays or X-rays. These rays penetrate flesh, blood, muscles, paper, leather, wood, rubber and many other substances which are opaque to light.

An instrument called a fluoroscope has been devised, which consists of a tapering box provided with an opening into which the upper part of the face fits closely to exclude the light. At the other end of the box is placed a screen covered with the crystals of calcium tungstate. This salt possesses the property of fluorescing when brought within

the influence of the X-rays. By fluorescence is meant the property of becoming self-luminous when exposed to the action of light. Any body opaque to X-rays, placed on the outside of the fluorescent screen, and between it and the Crookes tube, casts a shadow upon the screen, which may be seen by looking through the opening of the fluoroscope. If the hand is held in front of the screen, a person can see the shadow of the bones of the hand. The bones of the hand are opaque to the action of X-rays.

A Crookes tube is a hollow glass bulb exhausted to a high degree of vacuum, say to one one-millionth of an atmosphere (an atmosphere being equal to a pressure of 15 lbs. to the square inch)

Fig. 103 shows the manner in which the instruments used for the production of X-rays may be connected.

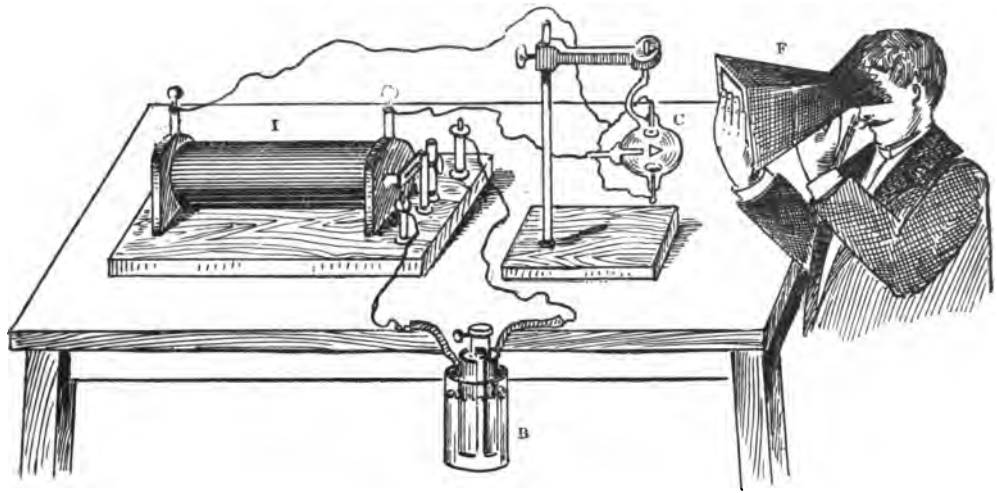


FIG. 108.
F, Fluoroscope; *C*, Crookes Tube; *I*, Induction Coil; *B*, Battery.

LESSON XLVI.

REVIEW.

130. *The attraction between magnets* and iron is called Magnetic Attraction. The magnetic attraction of the earth causes the magnetic needle, or any magnet freely suspended, to point north and south.

131. Like magnetic poles repel, unlike poles attract each other.

132. A piece of soft iron remains magnetic only while near to, or in contact with, the source of its magnetism.

133. The direction which a magnetic needle takes is called the Magnetic Meridian.

134. The declination of the needle is the angle which the magnetic meridian makes with the great circle which passes through the geographical poles.

135. The angle at which the needle inclines to the horizon is called the dip of the needle.

136. *The attraction of electrified bodies* is called Electric Attraction.

137. There are two kinds of electricity, positive and negative.

138. Like electricities repel each other; unlike electricities attract each other.

139. The purpose of lightning rods is:
1st, to attract electric currents;
2d, to conduct them safely into the ground.

140. Describe the Electroscope.

141. Bodies may be electrified either by *contact* or *induction*.

142. Describe the electrophorus.

143. Explain its action.

144. Describe the Leyden jar.

145. A Toepler Holtz Machine is a device for generating and collecting large quantities of electricity by induction.

146. Briefly describe it.

147. The mutual contact of two different metals (or of zinc and carbon), placed in a certain liquid, produces chemical electricity.

148. Chemical electricity travels in a circuit from its source and back again.

149. The unit of electrical resistance is the ohm.

150. The unit of strength of current is the ampere.

151. The unit of electro-motive force is the volt.

152. Soft iron is magnetic, when an electric current passes around it.
When the current is interrupted, it ceases to be magnetic.

153. A soft piece of iron, which is made into a temporary magnet while an electric current flows around it, is called an Electro-Magnet.

PART VIII. — SOUND.

LESSON XLVII.

PRODUCTION OF SOUND.

70TH EXPERIMENT. — **Insert the blade of a knife** between the horizontal joints on the side of a desk or table; take the free end of the handle, press it downward as far as convenient, and then let go; a noise will be heard, and the knife will be seen to move up and down very fast until it comes to rest. This is a swinging or oscillating motion, similar to that of the pendulum of a clock. All elastic bodies oscillate when left to themselves, if drawn out of their state of equilibrium. Their oscillations, if sufficiently rapid, and if carried through the air to the ear, are heard by us and then said to be *sound*.

A sounding body is always in a state of oscillation or vibration.

71ST EXPERIMENT. — **Take a tuning fork** and strike it against a table, so as to set it vibrating. Then plunge the ends in a tumbler of water. The water on the surface will be thrown off in the form of a spray.

Again strike the tuning fork and hold it against your teeth. The vibrations of the fork will be distinctly noticeable.

Sound is an impression made upon us by rapid waves or oscillations of some elastic body, transmitted to the ear.

72ND EXPERIMENT. — **Place an alarm clock** on a thick layer of loose cotton, under the receiver of the air-pump. You will notice that the sound of the alarm of the clock is distinctly audible. As the air is gradually exhausted from the receiver, the sound becomes feebler and feebler, and it would cease altogether if a perfect vacuum could be obtained.

Sound is not transmitted through a vacuum, for the reason that in a vacuum the medium of transmission, the air, is wanting. For the transmission of sound an elastic medium is necessary. This medium is usually the air, but all gases, liquids and solids, transmit sound.

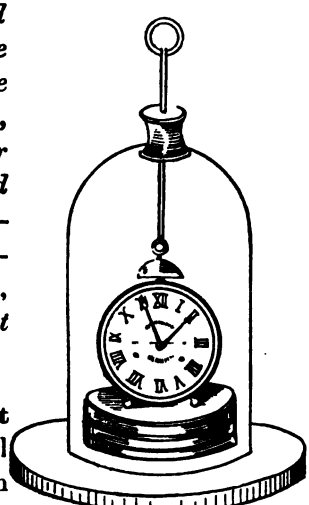


FIG. 104.

73RD EXPERIMENT. — **Let a few drops of water** fall into a vessel filled with water. At first the water is depressed, but quickly rises again. This vibratory motion is communicated to the remaining water. The water shows it

in the circular elevations (rings) round the point of contact.

So when a bell is set to vibrate, it communicates its own vibrations to the air around it and the air in turn transmits its vibrations to the ear. On water, the vibrations are rings; in air, spheres of compressed air, alternating with spheres of rarefied

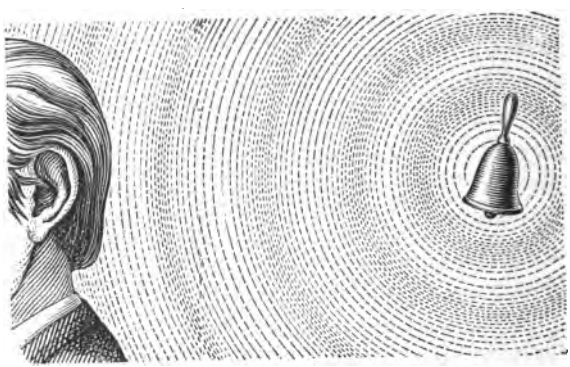


FIG. 105.

air. (Fig. 105.) So that we have spherical shells of compressed and rarefied spheres of air continually following one another, as they expand outward in regular order, like the circular water waves around the place, where the water drops fell into the vessel filled with water. (*Sound is transmitted by spherical waves of rarefaction and condensation in an elastic medium.*)

Familiar Facts.— The sounding-board of a piano vibrates while the instrument is being played; this may be seen if a pin or other small body be placed on it. Blowing into a pipe sets the air vibrating. In windy weather the church bells of a city may be heard farther off than usual, at a place which lies in the direction of the wind; while at a place nearer by, but in an opposite direction, they may not be heard at all.

Noise and Sound. — The discharge of a cannon; a clap of thunder, or the crack of a whip, each consists of a sudden blow which strikes the ear and makes a "noise." Noise is produced by a single sudden blow. But a quick succession of air-waves sufficiently strong to affect the ear, produces *sound;* and if the sound is more or less pleasing, it may be called *musical sound.*

74TH EXPERIMENT — *Conduction of Sound.* — **Take a board** about ten feet long, or longer; place an observer with his ear close to one end of it. A slight noise, such as the scratch of a pin, made at the other end of a board, which otherwise could not be heard, will then be distinctly audible to the listener at the end of the board.

75TH EXPERIMENT. — **Remove the bottoms** of two small tin cans and substitute for them pieces of rubber or bladder tightly wound on with the ends

of a long string. Stretch the string taut. A conversation may now be carried on between persons a considerable distance apart, by using one cup as a mouthpiece and listening at the other, as shown in Fig. 106.

The roaring of cannon, the hoofs of horses, the marching of soldiers, and the motion of a railway

FIG. 106.

train are heard at a greater distance by him that places his ear on the ground.

Solids conduct sound better than air.

Water also conducts sound well. This is attested by divers, who can readily hear the sounds from the shore.

Inelastic bodies, such as woven tissues, cotton or hay, are bad conductors of sound. Fog also transmits sounds poorly.

Velocity of Sound in Air. — If a cannon is fired off at a distance of about 1,100 feet, the flash is seen instantaneously, but the report will be heard a second later. At twice that distance, the report will be heard two seconds later. From the time which elapses between the flash of a gun on a vessel in distress, and the hearing of the report on the shore, the distance of the vessel may be found. Thus, if ten seconds have elapsed, the vessel is about 11,000 feet, a little over two miles, distant.

In the same way the distance of lightning can be calculated by observing the time which elapses between the flash of lightning and the peal of thunder.

The length of space passed over by sound in a second, is called the *velocity of sound.* The velocity of sound in the air depends on the density and on the temperature of the air. It is about 1090 feet per second at the temperature of the freezing-point. It is much greater in liquids, being, in water, about 4,650 feet per second; and greater still in solids.

Read "*Wonders of Acoustics,*" in Illustrated Library of Wonders.
Read "*The Ear*" in "Human Body" — Illust. Library of Wonders.
Read "*Sounds and Echoes,*" p. 268, in "Things not Generally Known."

LESSON XLVIII.

INTERFERENCE AND REFLECTION OF SOUND.

Interference of Sound —76TH EXPERIMENT. — Take two tuning forks of the same pitch and place a piece of sealing wax on the prong of one of them thus flattening its note, and decreasing its rate of vibration. Now note, that the united action of both will at first produce a sound greater than that given by either alone, gradually become very feeble and then increase again in loudness. This action produces a series of palpitations which are called *beats*.

77TH EXPERIMENT. — **Hold a vibrating** tuning fork near the ear and slowly revolve it between the fingers. During one revolution four positions will be found in which the sound is distinctly audible and four positions in which there is silence.

This phenomenon illustrated in Experiment 76 and Experiment 77 is called the *interference of sound* and is always produced when waves of condensation and rarefaction meet in such a manner as to neutralize each other.

Reflection of Sound. — Sound waves are reflected, like light and heat waves, in such a manner

as to make the angle of incidence equal to the angle of reflection. The laws are much more easily studied in the case of light. They will be discussed in the chapter on light.

The echo and whispering galleries are examples of the reflection of sound.

LESSON XLIX.

OSCILLATING STRINGS, RODS AND PLATES.

78TH EXPERIMENT.— Let a string be stretched between two pegs, *A* and *B*, Fig. 107. If now, a fiddle-bow be drawn across the string at *a*, the string will oscillate in its entire length, so as to appear like a film; the greatest oscillation being at the middle. The tone produced by the string in such a case is called the "fundamental" tone of the string.

If a thin slice of wood — or a "bridge" — be placed edgewise under and against the string, at its center *b*, and the bow be then drawn across at *a* the

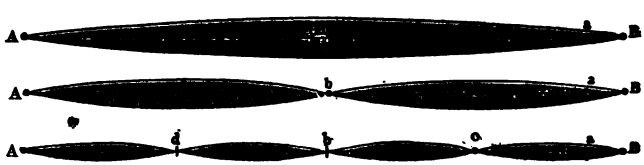


FIG. 107.

string can no longer oscillate in its entire length, because point *b* cannot move. At first, string *bB* oscillates, and the tone which it gives out is the next higher octave of the fundamental sound of the

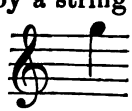
entire string AB. String bB has one-half the length of string AB. But the oscillations of bB are communicated to bA which now oscillates the same as bB, producing the same tone. Under these circumstances the number of oscillations made by bB is the same as that made by Ab. This number is twice as great as the number of oscillations made by AB when oscillating in its entire length. If, for example, AB has the tone of $= g$, then bA or Ab will produce which latter tone is the next higher octave of the former g, and will make twice as many oscillations per second. If, for example, the former g makes 198 oscillations per second, then the g sounding the next higher octave makes $198 \times 2 = 396$ oscillations.

Hence, if a string be divided into two halves, each half will make twice as many oscillations per second as the original string, provided the strain upon each half is the same as before.

If the bridge be placed at point c of string AB, and the fiddle-bow be drawn across Bc at x, then this piece Bc, having one-fourth the length of AB, will oscillate four times as rapidly as the entire string AB.

But at the same time that *Bc* oscillates, the other portion, *Ac*, of string *AB* divides itself into three distinct portions, each of the same length as *Bc;* and each portion oscillates as if it were a separate string. Thus, *bc* makes the same number of oscillations per second as *Bc;* and so does *bd*, or *Ab*.

The fact that points *d* and *b* and *c* remain at rest while strings *Ab*, *db* and *bc* oscillate, may be shown by placing paper-riders — minute bits of paper bent so as to sit on the string — at *d* and *b* and at a few intermediate points. When the bow is drawn across *a* the riders *between* the points will either fall off or be thrown into a state of lively commotion, while the riders at points *db* will remain still. The points *b*, *d*, *c*, Fig. 107, are *nodal* points. The vibrating parts between these points are called *segments*.

If string *AB* produces , then the tone given out by a string of one-fourth the length of *AB* will be 

If a string be divided into four equal parts, each fourth will make four times as many oscillations per second as the original string, provided the strain is the same as before.

Whenever a cord vibrates as a whole, giving forth, as we have stated, its fundamental tone or lowest tone, it also separates into segments at the same time. Thus we have the full or fundamental tone of the entire string together with the higher notes produced by the vibration of its parts. The notes produced by the latter vibrations are called *overtones* or *harmonics*. The commingling of these two kinds of vibrations enables us to distinguish the tones of one musical instrument from another and is called *timbre*.

The greater the number of oscillations of a string per second, the higher is the sound given out by the string. Now, as we have seen, the greater the length of an oscillating string, the smaller the number of its oscillations per second and the lower its sound, and the smaller the length of an oscillating string, the greater the number of oscillations per second and the higher its sound. This explains why in a piano the shorter strings produce the treble or higher sounds, and the longer strings the base.

The position of a note in the musical scale is called its *pitch*. It depends upon the rapidity of vibration of the sounding body. By a vibration is meant a to or fro motion of the string.

String Instruments.— The best known among this class of musical instruments are: The piano, the violin, the banjo, and guitar.

79TH EXPERIMENT.— **Strike a tuning fork forcibly** and then hold it up in the air; its tone will be faint. But if after being struck, it is set upon an empty box after the manner of Fig. 108, or on the body of a violin, its tone will be greatly strengthened. The reason of it is, that the body of the violin, or the sounding board of a piano, is set to vibrate by the oscillations of the string, by which the sound of the string is increased.

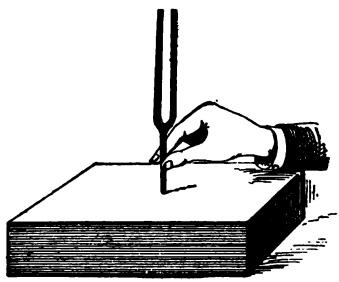


FIG. 108.

Reinforcement of Sound.— The sounding board of a piano, or the body of a violin, serves to "reinforce" the sound.

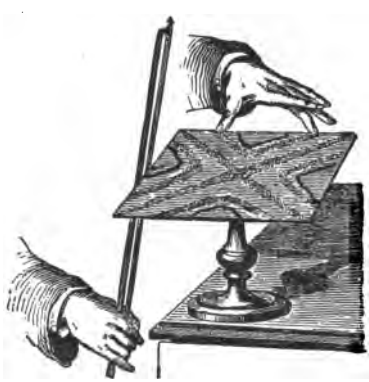


FIG. 109.

80TH EXPERIMENT. — **Fasten a plate of glass** or metal in a horizontal vise as shown in Fig. 109. Sprinkle fine sand on the plate and draw the bow of a violin lightly over one edge. The sand will be thrown off from the parts in vibration and

will gather on lines of rest. These lines are called nodal lines. In this way, an almost infinite number of nodal lines may be obtained, forming beautiful and symmetrical figures.

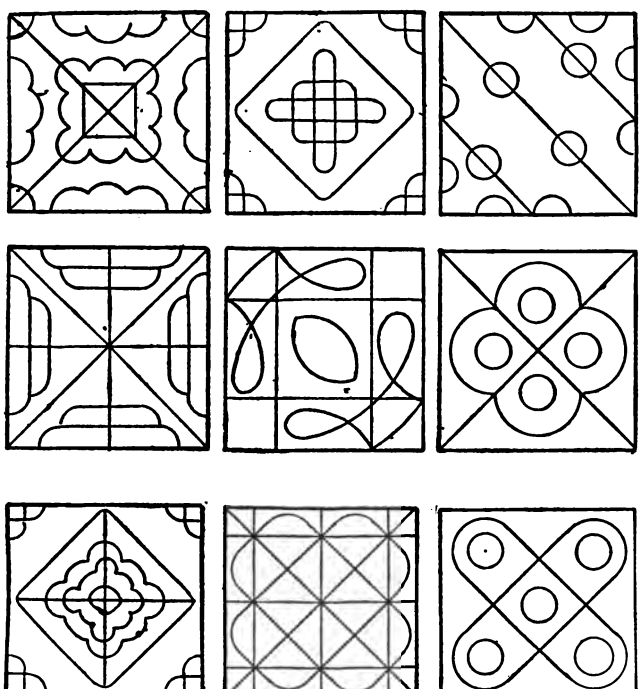


FIG. 110.

Fig. 110 shows some of the symmetrical forms that may be obtained in this way.

The vibrations of elastic solids bear a general resemblance to those of cords.

LESSON L.

WIND INSTRUMENTS.— PHONOGRAPH.

81ST EXPERIMENT.— **Hold a vibrating tuning fork** over the mouth of a tall jar, and carefully pour water into the jar. When the water fills the jar a certain level, the sound of the fork will be greatly increased by the vibrations of the column of air within the jar. The loudness of sound will be diminished at any point above or below this level. (Fig. 111.)

FIG. 111.

A hollow globe of proper size, with an opening on one side, will reinforce sound in the same way. *Such bodies are called resonators.*

Organ Pipes. — Wind instruments produce musical notes, by the oscillation of the column of air which they inclose. The column of air vibrates

as a whole, giving forth its fundamental tone, or in parts, just like a string, see Fig. 107. Organ pipes are simply resonant tubes. (Fig. 112.) The air in such pipes is set in vibration by oscillating reeds or by air driven through a mouthpiece like a whistle's instead of by the fork as in Fig. 111.

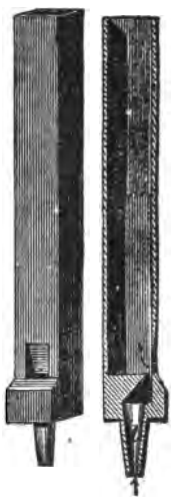


FIG. 112.

The Phonograph is an instrument used for recording and reproducing the vibrations of sound. It consists essentially of a cylinder of metal *C*, mounted on the axis *A B*, turned by the crank *E*. A hollow cylinder of wax, which fits over the cylinder *C*,

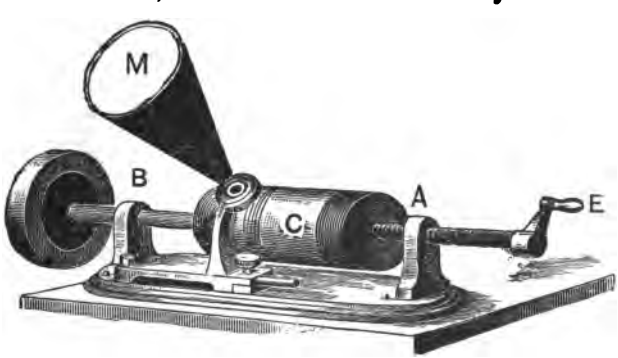


FIG. 113.

and which may be removed, receives the impressions made by a delicate chisel attached to a

glass plate which fits over the bottom of the mouthpiece *M*. The chisel (not shown in the cut) rests upon the wax cylinder, and when we speak or sing into the mouth-piece the vibrations of air are communicated to the glass plate at the bottom of the mouthpiece and the delicate chisel indents the wax. While talking into the mouth-piece *M* the crank must be turned uniformly.

After the line of indentations has been made on the wax, the cylinder is set back to its starting point.

If the crank is again turned, the chisel will follow the indentations in the wax, and so vibrate exactly as it did when it made these impressions. The vibrations of the chisel will be communicated to the plate and by the plate to the air. Thus the words spoken into the mouthpiece will be repeated.

In Edison's improved Phonograph the cylinder is turned by an electric motor.

PART IX. — HEAT.

LESSON LI.

HEAT — SOURCES — CONDUCTION — CONVECTION — RADIATION.

82ND EXPERIMENT.— **Strike a piece of flint** and steel together; sparks will fly off.

Familiar Facts.— After dark, sparks may be seen under foot when we are walking on a stone pavement, or when a horse is galloping. In these cases, iron (the nails) has forcibly struck against stone. The sparks which we see are minute particles of iron or steel, heated to redness by *friction, or percussion.*

83RD EXPERIMENT.— **Rub a key,** or a copper coin, on the floor. It will soon become heated.

84TH EXPERIMENT.— **Try to ignite a match** by rubbing it gently on a piece of smooth glass. It will not burn, because there is insufficient friction; it merely glides over the smooth surface. But if rubbed against a rough surface, such as the floor or a brick, the match presses against the projecting parts of the rough surface; owing to the friction thus produced it becomes heated and ignites.

Familiar Facts.— Wagon wheels have so much friction at their axles, that unless properly greased,

they may take fire. He that lets himself down by a rope has his hands blistered. On a cold day, we sometimes rub our hands together. Saws and augers, after being used, feel hot; a piece of India-rubber, warm. This shows that *Friction produces heat.* It shows, also, that *Motion may be converted into heat;* for friction is motion arrested.

Joule's Experiment.— The exact relation which exists between friction or work and heat was first demonstrated by Joule, an English physicist. The principle of this form of apparatus is shown in Fig. 114.

The two weights w and w' fall through known distances under the action of gravity. By so doing they turn a paddle in the copper vessel B, filled with water. The resistance offered by the water to the motion of the paddles converts the friction into heat. The rise in temperature multiplied by the weight of the water gives the amount of heat developed.

He found that a pound weight falling vertically through a distance of 772 feet will generate enough heat to raise one pound of water through one degree. We have learned that the work done by a weight of one pound falling through one foot is 1 footpound. Hence to heat one pound of water one degree (*a heat unit*) is equivalent to 772 ft.-lbs. of work.

Besides friction, the sun, plants, combustion and animal heat are sources of heat.

85TH EXPERIMENT.— **Hold a short wire in the flame of a burning lamp. It will be felt, that even the part of the wire which is not in the flame, is**

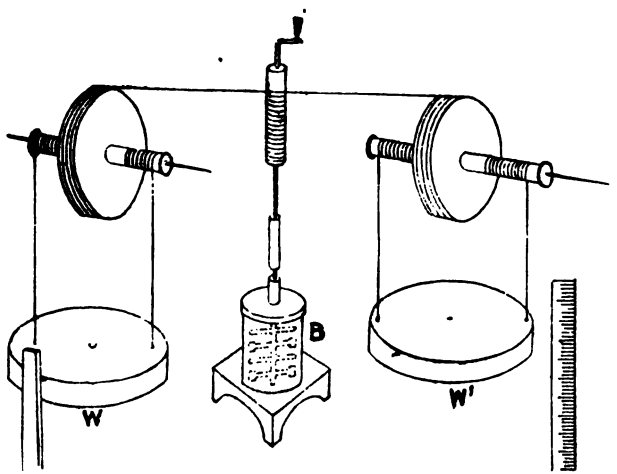


FIG. 114.

heated; and that the heat increases so that we must soon drop the wire. It is plain that the heat of the flame was imparted first to one end of the wire, and that it was gradually communicated to the remaining parts of the wire. This shows that *Heat may be*

communicated by passing successively from any part of a body to the remaining parts. This communication is called Conduction of Heat.

86TH EXPERIMENT.— **Hold a taper,** a straw, or a thread in the flame. It may burn quite near your fingers without hurting them.

87TH EXPERIMENT.— **Take up the wire again** (85th Exp.), but wrap a strip of paper, or cloth, around the end in the hand. If held in the flame again, there is scarcely any heat felt. Tea-pots and soldering-irons usually have wooden handles. Why?

88TH EXPERIMENT.— **Place a wire** and a piece of wood upon a heated stove, and let them remain there for a while. Both obtain the same temperature; yet, if touched with the hand, the wire *seems* to be the warmer. This is owing to the fact that, being a good conductor, it instantly *imparts* all its heat to the hand. If you touch a cold iron bar, it instantly *takes* heat from the hand, and, therefore, *seems* cold.

Metals are good conductors of heat. Paper, wood, cotton, wool, fur, feathers, ashes, snow, ice, straw and air, are bad conductors of heat.

89TH EXPERIMENT.— **Put a few** very small pieces of paper or saw-dust in a beaker of water and

apply heat (Fig. 115). You will soon see the saw-dust ascending and descending. The water near the bottom becomes heated and rises to the top. The cold water above sinks to the bottom, thus establishing ascending and descending currents.

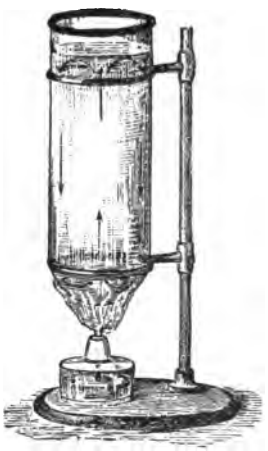


FIG 115.

This method of communicating heat is called convection.

90TH EXPERIMENT.— **Fill a test tube with water. Place a chemical thermometer in the tube as shown in the figure. Apply heat near the surface. The water will boil, while the thermometer, which registers the temperature of the water at the bottom will scarcely be affected.** *Water and all other liquids are poor* **conductors of heat.**

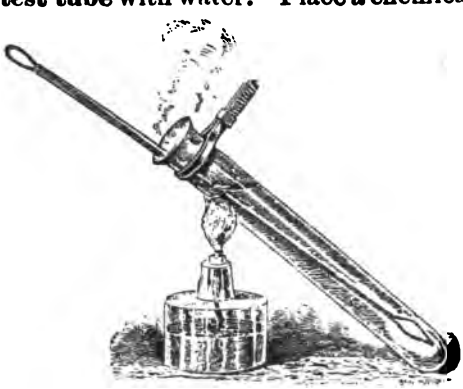


FIG. 116.

91ST EXPERIMENT — *Convection in Gases.*— **Shreds of cotton,** or small strips of paper, held over a heated stove or register, or over a lamp flame, will move upward, and, if let go, they will ascend. The air above the source of heat is heated. Paper balloons in which the air is heated by a fire underneath, rise in the air. The air in the balloon being heated, it expands, and being expanded, takes up more space than before, and, therefore, has less specific gravity than it had when cold. Now, as air rises in bubbles through water, so does heated air ascend in currents through the colder air.

92ND EXPERIMENT.— **Insert one end of a rod** upright in a cork, and stand the whole on a heated stove or register. Suspend from the top a band of paper, cut in the shape of a spiral; the upward current of hot air will cause it to revolve.

93RD EXPERIMENT.— **Bring a thermometer** near the floor of a room; then, near the ceiling. It will be seen that near the ceiling the air is warmer than below. *Heated air rises.*

94TH EXPERIMENT.— **If a window** in a heated room be opened above and below, the flame of a burning candle, held in the opening above, will be blown *from* the room; if held in the opening below, *into* the room. This shows that the colder air from out-doors rushes into the room from below, while the heated air of the room flows out above. The

colder air is confined to the lower parts of a room, because it has greater specific gravity than heated air.

Familiar Facts.— Wherever a fire is burning, a current of air, or *draught*, is produced. A draught is noticed when we pass from the sun into the shade; for where the sun shines, warmer air ascends, and is replaced by the colder air from below. Chimneys serve to increase the draught, because they inclose a tall column of heated air, which has less specific gravity than the outer, colder air. The latter presses in with increased force proportionate to the height of the chimney. If a handkerchief be tied around the small openings under the burner of a lighted lamp, the flame will be extinguished. The same happens, also, if the top of the chimney is covered with a piece of glass; in this case the draught is stopped because the heated air can not pass out, and consequently no fresh air come in.

Heated air rises; colder air takes its place.

Familiar Facts.—Near heated ground the air ascends and is replaced by colder air. This causes our atmosphere to be in constant motion. The currents thus produced are called *Winds.*

Application.— Chimneys (in lamps, stores, factories, etc., etc.). Ventilation of rooms and halls.

95TH EXPERIMENT. — **Hold your hand** in front of a hot stove. It becomes heated. This is not effected by conduction, for the hand does not touch the stove, nor by convection, for if the air could be exhausted from the space between your hand and the stove, the heat would still reach the hand. *This method of communicating heat is called Radiation.*

The sun heats the earth in this manner.

LESSON LII.

EXPANSION.

36TH EXPERIMENT. — **Bend an iron rod**, such as *B A C* in Fig 117, so that its ends *F G* face each other. Then insert a metallic rod, *D*, tightly between these ends. Next, support *B* and *C* so that the whole rests in a horizontal position, and heat the middle portion of the rod *B A C* by means of an alcohol flame placed directly under it; rod *D* will soon drop. This proves that ends *F G* have moved away from the rod, because portion *A* has been expanded, that is, lengthened by heat. After *A* has cooled off, the rod fits tight again, which shows that in cooling, portion *A contracted.*

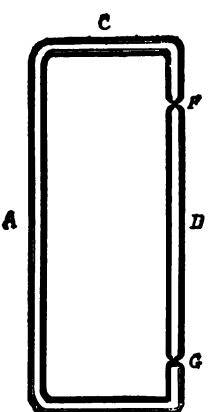


FIG 117.

Familiar Facts. — **A cold tumbler** placed on a heated stove will crack at the bottom. As it gets hotter below than above, it suddenly expands below more than it does above, and so the tumbler must break. — A bladder, filled with air and tied up at the end, expands if near a hot stove or register.

The air inside becomes heated, and heated air takes up a greater space than cold air. The rails on a railroad track are laid so that their ends shall be at a slight distance from each other; in summer their ends are very nearly together; in winter they are farther apart. Tires are heated nearly red-hot before they are placed on carriage wheels, for they are then wider, and, on cooling, fit tightly to the wheels.

97TH EXPERIMENT.— **Fit a long narrow tube** in the neck of a flask by means of a cork. Fig. 118. Fill the flask with water and apply heat. The water will now rise in the long narrow tube.

FIG. 118.

98TH EXPERIMENT. — Fit a long narrow tube in the neck of a flask like that used in Experiment 97. Invert the end of the tube in a beaker of water. Apply heat to the flask. The air, confined in the flask, expands and comes out in bubbles through the liquid.

Heat expands all bodies.

Temperature.— A substance is said to cool when it parts with sensible heat, that is, with such heat as may be felt. In the previous instance the tires lose most of their sensible heat. The amount of sensible heat which a body has, is its temperature.

Questions.— 1. Why may ice be kept as well in a feather bed as in an ice chest?

2. Why do mittens keep the hands warmer than gloves with fingers?

3. Why does snow melt more readily on a plank than on a rock?

4. Why are steam-chests and steam-cylinders often covered with wood?

5. Why are the walls of safes often filled with fine ashes?

6. Why do wide garments keep us warmer than tight ones?

7. Why are frame houses warmer than stone houses?

Application of Conducting Substances.

I. Good Conductors.— They conduct heat very rapidly, and are therefore applied where *heat is to be diffused quickly.* Thus, to boil water and roast meat, iron vessels are used. Iron stoves are heated in very little time.

II. Bad Conductors.— They conduct heat very slowly, but they also part with it slowly; for this reason we apply them where heat or cold is to be retained. *They serve to prevent a warm body from cooling off, and a cold body from becoming heated.*

Familiar Facts. — To warm a tumbler on a heated stove, a piece of *paper* should be placed between the glass and stove; otherwise the glass may crack. In winter, pieces of heated *wood* are laid in sleighs to keep the feet warm. *Boards* are placed on pavements, and horsemen often use *wooden* stirrups, because wood does not withdraw the warmth from the foot.

Cotton quilts, woolen garments, blankets and furs keep the body warm in winter; they neither allow the warm air surrounding the body to pass off, nor do they permit the cold external air to enter. In cold countries animals have very thick *fur;* in our latitude some have thicker fur in winter than in summer. Northern birds have thick *feathers.* Feather beds are in favor with persons fond of sleeping very warm. Blast-furnaces are sometimes provided with double walls, and the space between is filled with *ashes.* A cover of *snow* retains the heat of the earth; thus it protects the winter grain from the cold. The Esquimaux build themselves huts of snow and *ice.* Tender trees, vines, and pumps are covered with *straw* in winter to protect them against the cold. Ice houses are thatched with straw, and their walls filled with sawdust, to maintain the atmosphere in them steadily cool.

Read "*Heat,*" by J. Abbott. Harper & Brother.

LESSON LIII.

MELTING — BOILING — HEAT UNITS.

99TH EXPERIMENT.— **Place a vessel** containing ice over a fire (a spirit lamp or Bunsen burner). Constantly stir it. Place a thermometer in the mixture of ice and water and note that the thermometer will indicate a temperature of 32° F. without changing, so long as any ice remains unmelted. Increase the amount of heat, the ice will melt more rapidly but the temperature will remain the same.

During fusion or melting the temperature of a body remains constant if the pressure remains the same.

100TH EXPERIMENT.— **Place a beaker** containing water over a fire and boil the water. Introduce a chemical thermometer and notice that the temperature of the water will be 212° F. so long as the water continues to boil.

The temperature of a body remains constant during boiling if the pressure remains the same.

101ST EXPERIMENT.— Place a vessel filled with water at a temperature of 180° F. under the

receiver of the air pump and exhaust the air. The water will boil, although below its boiling point.

102ND EXPERIMENT. — Place a vessel containing ether under the receiver of the air pump, and exhaust the air. The ether will boil at the ordinary temperature.

103RD EXPERIMENT.— Boil some water in a flask. Allow the steam to drive out all the air above the water in the flask and then tightly cork it up. Removing the fire invert the flask and pour cold water upon it. The boiling will be renewed. The reason for this is that cold water condenses the steam above the water and produces a partial vacuum. (Fig. 119.)

FIG. 119.

If the pressure varies the boiling point varies.

Heat Units.— The amount of heat required to raise different substances in temperature varies with the substance. In order to compare the amounts of heat required by the different substances, in raising them one degree, water is selected as a standard. The amount of heat necessary to raise

one pound of water 1° F. is called a *heat unit.* The number of heat units required to raise one pound of any substance one degree is called its *specific heat.* The specific heat of water is greater than any other substance except hydrogen.

LESSON LIV.

EVAPORATION — FOG — CLOUDS — RAIN — SNOW — HAIL — DEW — FROST.

Water is one of the most necessary elements in human life. By the Hindoos and other pagan nations it was revered as a Deity. And the masses of bleached bones lying around the few wells in the desert show that during great heat the want of water may be fatal.

Familiar Facts. — Moisture on a slate or on a piece of paper will disappear very soon. Water in a tumbler, exposed to the air, constantly diminishes, and finally none is left. The water in streets, cisterns, ponds, and brooks gradually disappears. When water thus passes off into the air, we say that *it evaporates*. Evaporation takes place only at the surface of liquids.

By evaporation, water is changed into water vapor (or *aqueous* vapor).

Familiar Facts. — In summer our breath is invisible; in winter it is visible because it condenses immediately after leaving the mouth. In warm weather the vapors rising from rivers, swamps and lakes are invisible. There may be a great quantity of vapor in the atmosphere, and yet the vapor not

be seen. When the air near the earth is cool, the vapor becomes visible, and then we call it Mist or Fog. *Aqueous vapor coming in contact with cool air, forms Fog.*

The vapor may not be perceived below, but become visible higher up in the atmosphere. This takes place especially when warm, moist winds (south or southwest winds) come in contact with colder (north or northeast) winds. The vapor then forms *clouds.*

There seems to be no difference between fog and clouds.

Fog is clouds near the earth. Clouds may be said to be fog in the upper regions of the atmosphere.

Familiar Facts. — A piece of chalk, a piece of earth, a lump of coal, drop quickly; but dust, soot, and finely powdered chalk, descend very slowly. So the minute particles of which clouds and fog are composed may float in the air for a long time, because in this state their downward passage is resisted by the air. But when aqueous vapor comes in contact with cold air, its minute particles unite — form drops, and descend as *rain.* On their passage through the air, these drops, small at first, increase in size because they meet with more aqueous vapor in the air, which condenses upon them. The higher the clouds are in the air, the greater the rain-drops.

Rain is condensed aqueous vapor. In winter, the aqueous vapor in the atmosphere, when it condenses, freezes and forms minute crystals. These increase in size on their passage through the air, because more of the frozen vapor settles upon them, and reach us as *snowflakes.*

Snow is frozen aqueous vapor.

On stormy summer days, stones of ice sometimes fall from dense clouds, having an opaque kernel and a transparent rind. They may be disastrous to greenhouses and to the crops. They are called *Hailstones.* But it is not known why, in summer, such cold can be produced as to form solid masses of ice in the atmosphere.

Familiar Facts.— **Inhabited rooms** contain much aqueous vapor. A part of it is exhaled from our lungs. If, in summer, a tumbler is filled with cold water, it becomes cold; the aqueous vapor in the air around it cools off, and condenses, forming drops of water on the outside of the glass. If, in winter, a cold tumbler is brought into a warm room, vapor around the glass condenses, and forms moisture on the glass. Axes, iron safes and soda fountains are vulgarly said to "sweat." Moisture is deposited where a person breathes against a cold window-pane. The aqueous vapor of heated apartments condenses on cold window-panes and may run down as water.

Aqueous vapor when in contact with bodies sufficiently cold, is condensed into water.

Familiar Facts.— The glistening dewdrops which we admire in the early morning-sun, originate in the same manner. In clear weather, the objects on the ground cool off during the night; and at the same time the aqueous vapor in the air condenses about them. Grass and leaves, in general all pointed objects, cool more quickly, hence they have the most dew. If the sky is cloudy, the clouds act like a screen; they throw the heat back to the earth. Then the objects do not become sufficiently cold and no dew is formed. Sometimes there is no dew, and yet the sky is serene; this is owing to winds, which bring warmer air to the objects so that they do not cool off sufficiently. As rain is aqueous vapor condensed in the air, so *Dew is aqueous vapor condensed on solid bodies.* If, during the night, objects cool off to a greater extent, the dew which is formed, freezes. Then we call it Frost.

Frost is frozen dew.

Read "*Lakes, Springs, Rain, Dew, Ice,*" in "The Earth and its Wonders."

Read "*Atmosphere, Ocean, Rivers, Waterfalls,*" in "The Sublime in Nature." — Illustrated Library of Wonders.

Read "*Dew and Water-vapor,*" in "The Phenomena and Laws of Heat." — Illustrated Library of Wonders.

LESSON LV.

THERMOMETER.

The Thermometer. — The silvery substance in the thermometer is one of the few elements which have the liquid state at ordinary temperature; at an intense degree of cold — such as Arctic explorers experience — it freezes into a solid mass. Its name is Mercury or Quicksilver. If the mercury is heated, it expands; it rises in the tube as it expands. On cooling, it contracts, and falls. It may be heated by the atmosphere, that is, by the sun; or by hot water; by steam; by heated oil, or by the natural warmth of the human body. On examining the thermometer, you notice that it consists of a glass tube with a bulb below. Both tube and bulb are closed. The bulb and a portion of the tube are filled with mercury. Above the mercury is a vacuum. This vacuum is obtained by heating the mercury to a very high degree; its vapors then fill the tube, the open end of which is now fused; this closes the tube. The whole is then exposed to cold; this condenses the mercury-vapors into liquid mercury, leaving a vacuum behind. The frame is not an essential part of the thermometer. A little above the bulb is a point, marked Freezing Point. Everywhere on the earth, ice melts at the same degree of

temperature. So, after the tube is sealed and cooled off, it is placed in melting ice. Immediately the mercury sinks, because the cold contracts it. It occupies now a much smaller space, and when it has settled, its lowest point is carefully marked, either on the frame or by etching it on the glass tube. This point is called the "Freezing Point." It has also been found that all over the earth, water in low countries boils at the same temperature. So the thermometer is now held upright in the hottest steam issuing from boiling water. Heat expands all bodies; hence the mercury expands and is seen to rise in the tube. The point at which it rises is carefully marked; it is the "Boiling Point." The space between the two points has been divided into degrees. By means of these degrees, we are enabled to indicate the temperature which a body has acquired.

Read "*Expansion — Thermometer*," in "The Phenomena and Laws of Heat."

LESSON LVI.

THERMOMETER COMPARED WITH BAROMETER.

104TH EXPERIMENT.— **If the palm of the hand,** after being rubbed a little so as to be perfectly dry, is held to the thermometer-bulb, the mercury will rise to a point which marks the Blood-heat of the human body. It happens to be indicated on our thermometers by the number 99. This is owing to the fact, that in our country, and also in England, the space between the freezing and the boiling points is measured by very small degrees, of which there are 180 between those two points. Fahrenheit, a philosophical instrument maker, divided that space into 180 degrees. He commenced counting, however, not at the Freezing Point, but at a point below, which is the zero point of his scale; this brings the freezing point to 32°, and the boiling-point to 212°. In some European countries the Freezing Point is marked 0°, the Boiling Point 80°; that is, the space between the two points is divided into only 80 degrees. Each degree of this kind is much larger (how many times as large?) than one of the former kind, the Fahrenheit. From the name of the French philosopher who arranged this scale, its degrees are called *Reaumur*. Thus 80° *R*. is equivalent to 180° F. Far more conve-

nient than either of the two preceding scales is the one of Celsius. He divided the space between the freezing and the boiling points into 100 degrees.

The use of this division is gradually spreading. According to it 100° C = 180° F = 80° R.

The *minus* sign distinguishes numbers below 0.

	Centigrade.	*Fahrenheit.*
Boiling Point	100°	212°
	50°	122°
	25°	77°
Freezing Point	0°	32°
	—17⅞°	0°
	—50°	—58°

The healthiest temperature for any room is about 65° F. Our rooms should not be heated beyond that in winter. Thermometers should be placed at equal distance from stove or fire-place, and the windows, so as to show the mean temperature of the air in the room.

Questions.— If in New York the mercury stands at 80° above zero, how would the same temperature be indicated in Paris (according to C. degrees)? How in Berlin (according to C. degrees)? By what numbers would the blood heat point be indicated according to those scales? By what number is the point of healthiest temperature indicated in C. degrees?

Thermometer and Barometer Compared.

Four points in common:

1. Both instruments consist of a *glass tube.*
2. Both have *mercury* in their tubes.
3. Both have a *vacuum.*
4. Both have a *graduated scale.*

Four points of difference:

1. The thermometer tube is *closed above and below;* the barometer tube is *closed above but open below,* so that the pressure of air may reach the mercury within.
2. In the thermometer-tube, the mercury rises and falls on account of the effects of *heat and cold;* in the barometer-tube, the mercury rises and falls on account of the increase or decrease of *air-pressure.*
3. The thermometer has a scale of *degrees whose size is arbitrary* and may be different in different thermometers;
   the barometer has a scale of *inches,* and fractions of inches; its scale is of *less extent,* and only at the *upper part* of the tube.
4. Mercurial Thermometers may have *any length;* mercurial Barometers have *uniform length.*

LESSON LVII.

THE ATMOSPHERIC ENGINE.

If we look at a sewing-machine while it is in motion, our attention is immediately called to a long, upright rod, made to move up and down by the stroke of the foot. The rod being fastened to a wheel, it is evidently its up and down motion that causes the motion of the wheel and with it, that of the machine. You need but fasten a rod to the edge of a toy-wheel, and you may demonstrate the same. Motion in a straight line — *rectilinear* motion — is thus converted into *circular* motion.

This was known thousands of years ago; but, strange to say, the principle upon which the steam engine is founded, was not thought of until about 1690, A. D. At that time, Professor Papin, an exiled Frenchman, living in Germany, published a little work, in which he says: "There is a property peculiar to water, owing to which a small quantity of that liquid, if heated and converted into steam, acquires a force of elasticity which much resembles that of air. When cooled down, it returns to its liquid state, and loses its elasticity. I am, therefore, inclined to believe that machines may be constructed which are moved by the application of heat to water."

These words laid the foundation for the greatest change which human society ever experienced. The machine that effected this change has benefited humanity more than all the gold mines of the world. The steam engine not only reveals to us the hidden treasures of the earth; "it can engrave a seal; crush masses of obdurate metal like wax before it; draw out, without breaking, a thread as fine as a gossamer, and lift a ship of war like a bauble in the air. It can embroider muslin and forge anchors; cut steel into ribands and impel loaded vessels against the fury of the winds and waves." And when it flies with the rapidity of a bird, over land and water, hurling dense masses of steam and smoke into the air, does it not look like some gigantic monster that contains the strength and the power of thousands of men? Well may we admire the genius of man that can turn a force of nature to such wonderful account.

The simplicity of Papin's statement is demonstrated by his own application. Knowing that steam was elastic like air, he constructed an apparatus which, although its practical usefulness was impeded by its slowness, was the first steam engine ever built.

105TH EXPERIMENT.— **Papin's apparatus** may be illustrated by a test-tube (one of tin or brass is preferable, inasmuch as glass breaks easily), as shown

FIG. 120.

in Fig. 120 A small disc of wood, with a packing of thread around it to make it fit tight, is made into a piston, *P*, moving in a tube nearly air-tight, and attached to a rod. The tube is then filled with water about an inch high, which is made to boil over a flame after the piston is carefully placed in the tube. The generation of steam causes the piston to rise. *E* is an outlet for surplus steam, and made in the upper part of the tube. Between the water, when boiling, and the piston there is no air; the space is filled with steam. On immersing the tube in cold water, the rod descends again, because the steam below the piston is condensed by the cold, and because a vacuum is thus formed between the piston and the surface of the heated water. What is it that forced the piston down? The answer is: "Atmospheric Pressure."

In place of a small tube, Papin used a large iron cylinder, with proper piston and piston-rod. We can readily imagine how, by throwing at regular intervals a stream of cold water on the cylinder, he produced an up-and-down motion of the rod; and how the machine must needs have been slow — too slow to be practically applied. A steam-engine built upon the principle of Papin's — that is, one not worked by the expansive force of steam, but merely by atmospheric pressure — is not a steam-engine, but an "Atmospheric Engine."

Captain Savery, an Englishman, constructed at about the same time, an apparatus in which the steam served the purpose of raising water. The steam was generated in a separate boiler, and thence led into a chamber where it was condensed by cold water flowing over the chamber. But the apparatus was imperfect, and used only for pumping water. Still, his was the merit of having constructed the first Atmospheric Engine that ever received practical application.

Thomas Newcomen, a hardware man, and John Cowley, a glazier, both Englishmen, by their brilliant invention, completely eclipsed Savery's engine. They improved upon Papin's plan in this, that they generated the steam in a boiler — not in the cylinder — and that they condensed it, not by cooling the boiler from without, but by forcing a jet of cold water into the steam. The machine was put to immediate use in the coal-mines of England; and it is sometimes used even at present, in places where a great mass of water is to be pumped out.

It consists of the boiler, *A* (Fig. 121), where the steam is generated, and the cylinder, *B*, which is connected with the boiler by means of the pipe, *F*. When steam has entered the cylinder, and the piston *G* is raised, the stop-cock, *a*, is closed. This shuts off the connection between the boiler and the cylinder. The stop-cock, *b*, is then opened, and a jet

of cold water from the small reservoir, *C*, is thrown into the cylinder. This condenses the steam in the cylinder; a vacuum is formed below the piston, and

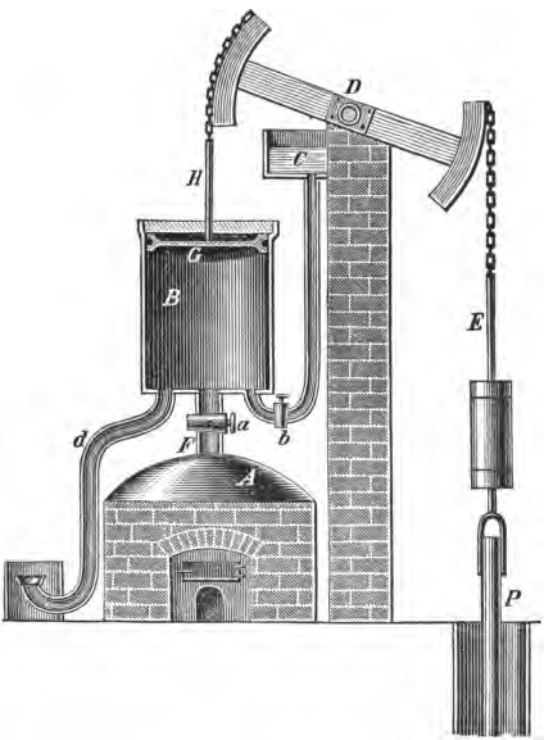


FIG. 121.

atmospheric pressure forces the piston down. The water from the condensed steam flows off through the pipe, *d*, into a reservoir with water. (At the end of *d* is a valve opening outward.) By means

of an iron chain, the piston-rod, *H*, is attached to a working-beam, which swings on the pivot *D*, and which is connected at the other end with the rod *E*. This rod is raised when the piston descends. When the stop-cock, *a*, is opened again, the steam rushes again into the cylinder; but as the force of pressure of the steam scarcely exceeds that of the air over the piston, the piston would not rise, were it not for the heavy weight attached to the rod, *E*. This weight falls whenever steam is let in under the piston, *G;* and in falling, forces one arm of the working-beam down, causing, at the same time, the piston at the other arm to rise. The rod *P* is the piston-rod of a pump, and is fastened to the weight.

In the Atmospheric Engine the piston is raised by Gravity, and lowered by Atmospheric Pressure.

State the principal points of Papin's engine; of Savery's; and Newcomen's.

Read "*H. Potter*," in "Inventions and Discoveries," by Temple. London; Groombridge.

LESSON LVIII.

THE STEAM-ENGINE.

Half a century had passed away. Newcomen's engine had been introduced into most of the coal-mines of England, when, in the winter of 1763, James Watt, a young mechanic, in Glasgow was employed by the University of that city to repair one of Newcomen's engines. The task which this man of uncommon mind was about to undertake, marks a new era in the history of steam-power, an era that finally resulted in the perfection of a machine which is an element of modern civilization. On trying the engine after he had repaired it, young Watt perceived that it was very imperfect. The principal defect consisted in this, that the machine used a great deal more steam than was needed for the motion of the piston. For when the stream of cold water was thrown into the cylinder, the steam was condensed; but at the same time, the cylinder was cooled down to such an extent, that when fresh steam was admitted again, a great quantity of it was wasted in reheating the cylinder; and thus there was a loss of money in direct proportion to the amount of fuel necessary for producing the quantity of steam equivalent to the quantity wasted. On calculating the loss, it was found that three-fourths of all the fuel used was wasted, that

is, employed in reheating the cylinder. The question with Watt now was, how can the cylinder, instead of being cooled, be kept permanently hot? In other words: How can the steam be condensed without at the same time cooling the cylinder?

Watt's genius solved the problem by an invention of surprising simplicity. He condensed the steam in a separate chamber, the *condenser*. It stood in a chest filled with water, and was connected with the cylinder by means of a pipe. Thus the steam could be condensed without cooling the cylinder, by simply leading it off. The immediate result was the saving of three-fourths of the fuel.

But Watt did not stop here. He noticed that the air entering the heated cylinder as the piston went down, also cooled the cylinder. This caused a waste of steam, as the cylinder, in order not to condense the fresh steam entering, had first to be reheated to 212°. To remedy this, he dispensed with the air entirely, in providing the cylinder with a cover pierced in the center so as to admit the piston rod air-tight. The air (atmospheric pressure) could now no longer act upon the piston; how then was the piston to descend? It was made to descend by allowing steam from the boiler to enter *above* the piston, through a pipe connecting the boiler with the upper part of the cylinder; and to pass out

again through a pipe connecting the cylinder with the condenser. Thus while there was a vacuum established in the lower part of the piston, steam was admitted into the upper part; the upper part then being made a vacuum by leading the steam off into the condenser, fresh steam was admitted into the lower part and forced the piston up. By this improvement, the steam not only served as a ready means for obtaining a vacuum, as in Newcomen's engine, but its expansive force was also made use of; and from that time Watt's engine was more than an atmospheric engine, it was a steam engine.

The atmospheric engine was "Single Acting;" it performed work only while the piston descended; the rise of the piston, as we remember from the preceding lesson, was effected by gravity. The power obtained by this machine was so small that it could not overcome the resistance of a wheel, and, therefore, it was used mainly for pumping water out of coal-mines.

By admitting steam alternately above and below the piston, Watt made the steam-engine "Double Acting," perhaps the most important of his improvements. For now, rotary motion could be produced, without which no locomotive or steamboat could ever have been thought of.

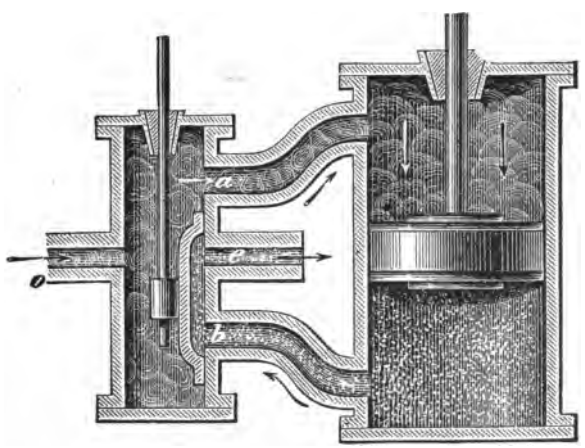
In all engines constructed by Watt, the power of the steam was low; it amounted scarcely to

more than 1¼ atmospheres (1¼ as much as the pressure of our atmosphere; that is 1¼ times 15 pounds to the square inch of surface.) The alternate condensation of steam on either side of the piston was, therefore, the only means of obtaining the up-and-down motion of the piston; for the feeble expansive force of the steam was totally insufficient to overcome the counter-pressure of the atmosphere. But by employing steam of greater expansive force — that is, steam capable of exerting a greater pressure, it was found that the condenser could be dispensed with, as the pressure of this steam was sufficiently great to move the piston against the resistance of the atmosphere. Engines usually having a steam-pressure of from 3 to 15 atmospheres (45 to 225 pounds of pressure to the square inch), and which, as a rule, have no condenser, but send their exhaust steam directly into the atmosphere, are called *High Pressure Engines;* while those generally working with a lower pressure, and always with a condenser, are called *Low Pressure Engines.*

Watt died in 1819, honored and admired by all who knew him. Within a short time after his death, five large statues were erected to his memory.

The admission of steam into the cylinder is now accomplished by means of a *sliding valve.*

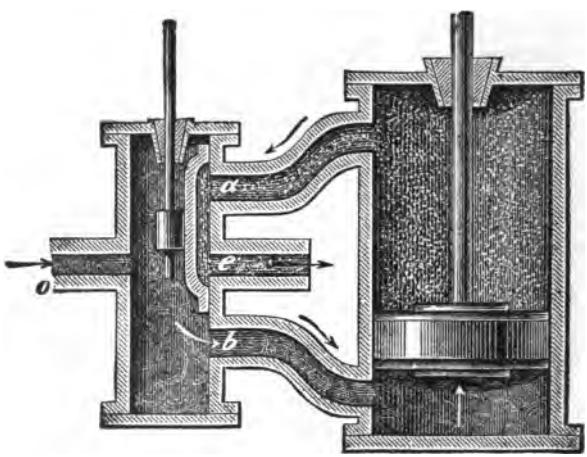
It is inclosed in a square box, called the steam-chest (see Fig. 122) which is attached to one side of the cylinder. When the steam from the boiler reaches the steam-chest through the opening, *o*, it fills the chest at once, and, as the sliding-valve keeps the opening *b* closed, presses through *a* into



Steam-Chest. FIG. 122. Cylinder.

the cylinder, of which it fills the upper part, and forces the piston down, because a vacuum has been formed on the other side of the piston, or, as in High Pressure Engines, by the expansive force of the steam. At the same time, however, the sliding-valve (which rises when the piston-rod descends, and descends when the piston-rod rises) has moved upward, and shut off the steam from *a* (see Fig. 123); the steam must now enter through

opening *b* and force the piston up. Meanwhile the old steam above the piston passes through *a* and *e* into a tube leading to the condenser. In a steam-engine which has no condenser, as, for example, the locomotive, the old steam passes through *e* into the air. After the piston has



Steam-Chest. FIG. 123. Cylinder.

arrived above, the process is renewed, steam passing above and below the piston which, as mechanics say, moves in a vacuum, or rather, in a space filled with steam.

When we look at a locomotive rushing past us we notice a horizontal iron rod moving back and forth. The rod connects two large wheels, and runs at one end in a wide cylinder. Next to this

cylinder is the steam-chest, a small square box. It is in the cylinder that the motory power is imparted to the engine. The main parts of the locomotive are the steam-chest, cylinder, piston, piston-rod, the large wheels, and the boiler.

The steam, by means of the sliding valve, causes the back-and-forth motion of the piston in the cylinder; by this, it causes the back-and-forth motion of the piston-rod; and by this, the revolution of the large wheels. The wheels roll on the track; they cause the locomotive to move onward, and the locomotive pulls the cars attached to it.

In Figs. 122 and 123 the exhaust *e* is too narrow. It should be considerably wider than either *a* or *b*.

Read "*James Watt*," in "Pursuit of Knowledge," Vol. II, Harpers.

Read "*The Locomotive Engine*," by C. Colburn. H. C. Baird, Phila.

Read "*Steam-Engine*," by David Read. Hurd & Houghton, New York.

Read "*The Railway and its Cradle*," — "*The Youth of James Watt*," — in "Inventions and Discoveries." Groombirdge & Sons, London.

LESSON LIX.

REVIEW.

154. Sound is an impression made upon us by the rapid waves or oscillations of some elastic body, which are transmitted to the ear.

155. *Noise* is produced by a single sudden blow. *Sound* may be produced by a quick succession of air-waves. If the sound is more or less pleasing to the ear, it may be called *musical sound.*

156. Sound is not transmitted through a vacuum.

157. Solids conduct sound better than air.

158. Inelastic bodies are poor conductors of sound.

159. The velocity of sound in air is about 1,100 feet a second. It is greater in liquids, and in solids greater still.

160. The best known string instruments are: The piano, the violin, the banjo and guitar.

161. The tone produced by a string oscillating in its entire length, is called its "fundamental tone."

162. If a string be divided into four equal parts, each fourth will make four times as many oscillations per second as the original string, provided the strain is the same as before.

163. Reinforcement of sound means the strengthening, or increasing, of the sound of a musical instrument.

164. Water is changed into water vapor (or aqueous vapor) by evaporation.

165. Water vapor, coming in contact with cool air, forms fog.

166. Clouds may be said to be fog in the upper regions of the air.

167. Snow is frozen water vapor.

168. Water vapor is condensed into water when in contact with bodies sufficiently cold.

169. Frost is frozen dew.

170. Friction produces heat, and motion may be converted into heat.

171. Heat may be communicated by passing successively from one part of a body to the other parts. This mode of communication is called *Conduction of Heat.*

172. Metals are good conductors of heat. Paper, wood, cotton, wool, fur, feathers, ashes, snow, ice, straw and air are bad conductors of heat.

173. Heat expands all bodies.

174. The amount of sensible heat which a body has is its temperature.

175. Heated air rises, because it has less specific gravity than cold air. This causes *Draught* and *Winds*.

176. The space between the Freezing Point and the Boiling Point in a thermometer is divided into degrees, by which the temperature of a body may be estimated. Fahrenheit divided it into 180 degrees; Celsius into 100 degrees and Reaumur into 80 degrees.

177. The freezing point in Fahrenheit thermometers is marked 32°; in the Celsius and Reaumur thermometers 0°.

178. In the old atmospheric engine the piston is raised by *Gravity;* and forced down by *Atmospheric Pressure*.

179. Low-pressure engines generally work with steam of about 1½ atmospheres. The steam pressure in high-pressure engines may be as high as 15 atmospheres.

180. In the locomotive, steam moves the piston by means of a sliding valve. The motion of the piston causes the motion of the piston rod, which makes the large wheels revolve. The revolutions of these wheels and their friction on the rails cause the locomotive to move.

GENERAL REMARKS.

181. When a stone is dropped upon the floor, the floor and the air over it are set vibrating by the concussion; which shows that *Force* may be converted into *Pressure*, and *Pressure* into *Motion*. (In this case the *force* is gravity; and the *pressure* is the result of the gravity of the stone when striking the floor.)

182. The motion of a train of cars heats the axles and wheels of the cars. This shows that *Motion* is convertible into *Heat*.

183. Heat expands all bodies; and since expansion implies motion, we can say that *Heat* is convertible into *Motion*. (Illustrated by the thermometer.)

184. Heat expands water into steam. The steam is in a state of expansion; its particles are in continual motion. A result of this motion is

the expansive force or pressure of steam. Hence, *Motion* is convertible into *Force* or *Pressure*.

185. The expansive force or pressure of steam disappears as soon as it has moved the piston of an engine. The motion of the piston is work that has been performed by the steam. *Force* or *Pressure* is here converted again into *Motion*.

186. *Force* or *Pressure* is convertible into *Motion of Masses*. (Illustrated by barometer and pump.)

187. RECAPITULATION.

a. Force or Pressure is convertible into Motion.
b. Motion is convertible into Heat.
c. Heat is convertible into Motion.
d. Motion is convertible into Force or Pressure.
e. Force, Pressure and Motion are convertible into one another.

PART X. — LIGHT.

LESSON LX.

NATURE OF LIGHT.

There are two hypotheses regarding the nature of light; one that a luminous body emits minute material particles, which travel through space in all directions and striking the retina of the eye produce the sensation of light; the other, called the *wave theory* of light, assumes that the molecules of a luminous body are in a state of very rapid vibration, that these vibrations are communicated to the ether, which is supposed to be an imponderable substance that fills all space, and that the ether transmits these vibrations in spherical waves. When these waves of ether strike the retina of the eye they produce the sensation of light.

LESSON LXI.

REFLECTION OF LIGHT.

When a ray of light falls on a body some of it is reflected or thrown back in all directions. If a ray of light, *I M* (Fig. 124), falls on a plane surface, *A B*, it will be reflected in the line *M R*. Draw the line *P M* perpendicular to the surface at the point where the ray of light strikes the surface. The angle *I M P* is called the *angle of incidence*. The angle *P M R* the *angle of reflection*. Careful measurement shows that the *angle of incidence is always equal to the angle of reflection*.

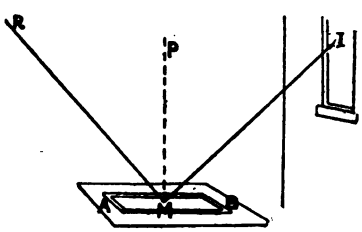


FIG. 124.

Familiar Facts. — Here is a pencil. What enables us to see it? It is not a self-luminous body; but there is diffused light in the room, and as the pencil has a more or less rough surface, every point on that surface receives some of this diffused light, and in turn *reflects* some of it. It does so by *radiating the light in all directions*. Of this radiated light, a portion enters our eye, and we say "we see the pencil," and may then describe it.

We see a looking-glass, owing to the light which is reflected from it by radiation. True, its surface is smoother than that of the pencil or of most objects; yet even in a looking-glass there are very many uneven places, from every point of which light is reflected by radiation. Were it not for that, we would not see the glass at all. The surface of a perfect mirror would be invisible.

All bodies reflect light by radiation. This is called *Radiant Reflection of Light.*

Mirrors.— All highly polished surfaces are mirrors. These are of two kinds — plane and curved. The curvature of the latter is usually spherical.

106TH EXPERIMENT.— **If a mirror** be placed in an upright position, and a small block be put in front of it, an image of the block will be seen in the mirror. This image represents the *form* of the block; and its position will appear to be as far behind the mirror as the block is in front of it. If the block be moved farther away from the mirror, the image will appear to move farther away from the mirror; and if the block be made to approach the mirror, the image will appear also to approach the mirror. But it will be seen that the *right* side of the block forms the *left* side of the image, and the left side of the block the right side of the image.

The reflection or image of the human figure in a vertical mirror appears to be as far behind the mirror as the person is stationed in front of the mirror. The image is erect and the same size as the person. But it is *left-handed;* a pencil, for example, in the right hand of a person will appear as being in the left hand of the image.

Formation of images by plane mirror.— We have seen in the above experiment that the image appears to be as far behind the mirror as the object is in front.

The position of the image and the direction in which it is seen may be drawn by first drawing every part of the image as far behind the mirror as they are in front. In Fig. 125, let *A B* represent the object in front of the mirror *M N*. *A B* must be considered a collection of luminous points, every one of which radiates light in all directions.

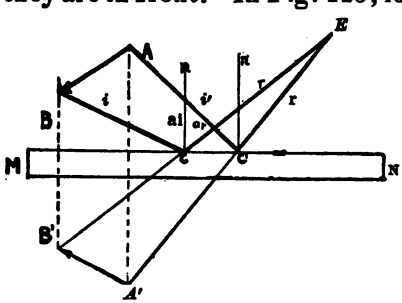


FIG. 125.

Part of the rays will strike the mirror and will be reflected according to the law given in Lesson LXI. namely *that the angle of incidence is equal to the angle of reflection.* Let *i* be an incident ray com-

ing from B, and striking $M\ N$ at c. It will be reflected in the direction of r, making $a\ i$ equal to $a\ r$. Then r will represent the path of the light reflected at c. If at E the ray of light enters the eye, then the point B will appear to be at B', which is as far behind the mirror as B is in front, and is also in the line $B'\ c$, which is a prolongation of the reflected ray r.

Similarly, draw i' to represent the path of light coming from A, and striking $M\ N$ at c'. Then r' will represent the path of the reflected ray. If r' enters the eye at E, the object A will appear to be at A', and also in the prolongation of the reflected ray r'. In like manner the images of points intermediate A and B can be obtained.

Multiple images.— If two images are at right angles, a luminous point placed between them will give three images.

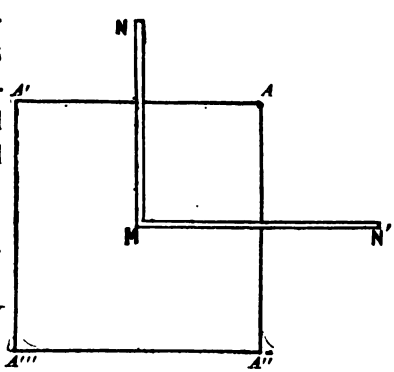


FIG. 126.

Let A be a luminous point between two mirrors $N\ M$ and $M\ N'$. Fig. 126. Then the image A' of the object A formed by the mirror $N\ M$ will appear to be at A'. A' is as far behind the mirror

$N\ M$ as A is in front of it. The image of A formed by $M\ N'$ will appear to be at the point A'' for the same reason. Now the point A' reflected by $M\ N'$ will appear to be at A'''. The point A'' reflected by $N\ M$ will also be at A''' superimposed upon it. Thus giving us three images of the point A.

If the angle between the two mirrors is diminished, the number of images will be increased. The number of images, formed by two mirrors, may be obtained by dividing 360° by the angle between the two mirrors, and subtracting *one* from the quotient.

The kaleidoscope is an optical instrument which illustrates this property of two mirrors. It consists of a tube containing two or three long mirrors, inclined to each other at an angle of 30 or 60 degrees. Pieces of colored glass, free to move, at one end of the tube, are seen through an eye-piece at the other end of the tube, multiplied by repeated reflections.

Familiar Facts.—Burnished metal plates, polished wood, the surface of water or mercury, the coating of mercury in looking-glasses, and even common glass plates when viewed in a very oblique position, exert both "Radiant" and "Specular" reflection of light. *Objects with polished surfaces reflect light radiantly and specularly.*

LESSON LXII.

FORMATION OF IMAGES BY CURVED MIRRORS.

Spherical mirrors may be either concave or convex.

Concave mirrors reflect light from the inner face of the mirror. Convex mirrors reflect light from the external face.

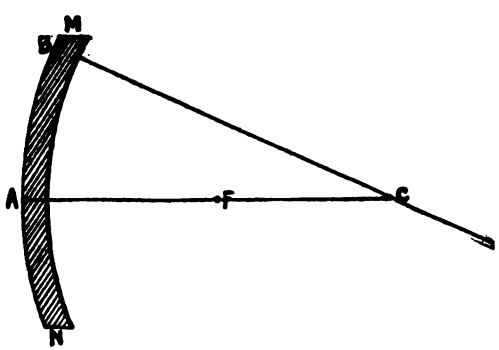


FIG. 127.

Let *M N* (Fig. 127), represent a cross-section of a concave mirror. *C*, the center of the sphere, is called the *center of curvature*. *A* is the vertex of the mirror. The straight line *A C* is called the principal axis. *F* is the principal focus and is midway between *A* and *C*. Any line *B C* passing

through the center of curvature and striking the mirror is called a *secondary axis*. It is also a perpendicular to the mirror *M N*, at the point *B*. For geometry teaches us that a *radius of a circle* is perpendicular to the circumference of the circle at the point of incidence.

If now a luminous point be placed on the principal axis, the image formed on reflection will vary in position and size with the distance of the point from the mirror.

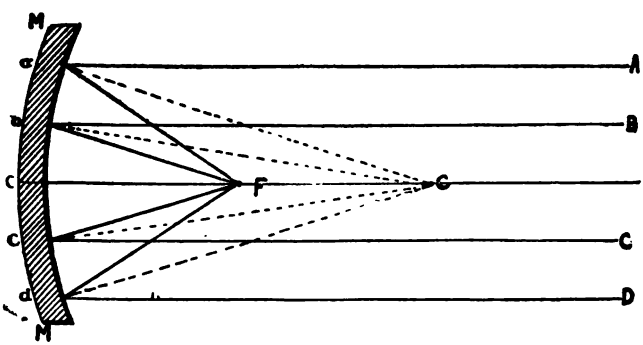


FIG. 128.

If the point is at an infinite distance, the rays of light coming from this point will be sensibly parallel to the principal axis (Fig. 128).

Let *Aa*, *Bb*, *Cc*, *Dd* represent rays of light coming from a point at an infinite distance, viz., the sun. These parallel rays will be reflected so as to make the angle of incidence equal to the angle of

reflection. Draw the perpendiculars *Ca*, *Cb*, *Cc*, *Cd*. Then the incident rays *Aa*, *Bb*, *Cc*, *Dd* will be reflected along the lines *Fa*, *Fb*, *Fc* and *Fd*, to the point *F*, which is the *principal focus of the mirror*.

Hence *parallel rays are reflected to the principal focus*.

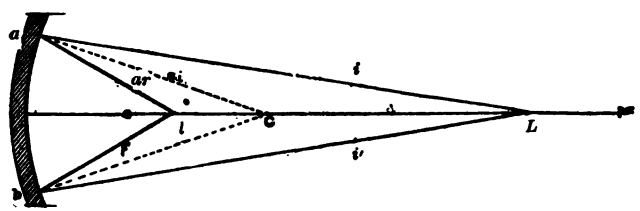


FIG. 128.

If the luminous point is at *L* beyond the center of curvature of the mirror (Fig. 129), the rays will converge at *l*. To find this, draw *i*, any incident ray from *L*; erect the perpendicular *ac* at the point of incidence *a*. Now draw the reflected ray *al*, making the angle of reflection *a r* equal to the angle of incidence *a i*. Now take any other ray, *i'* it will also be reflected to the point *l*.

Hence rays of light coming from a point L on the principal axis, beyond the center of curvature and at a finite distance, will converge at a point l, which is somewhere between F and C.

If the luminous point is placed at *l*, then the image will be at *L*. *Two points so associated that*

one is the image of the other, are called conjugate points.

It is obvious from an inspection of the above figures that the nearer the luminous point L approaches the center of curvature, the nearer will its conjugate focus l approach the center. Hence when L reaches C, the center of curvature, its image l will be superimposed upon it. If the luminous point L now approaches F, the focus, the image l will approach infinity, and when L reaches F the image l will be at an infinite distance.

It must be noticed that the image and the object are always on the same axis. If the object is placed at L (Fig. 130), the image l will be found

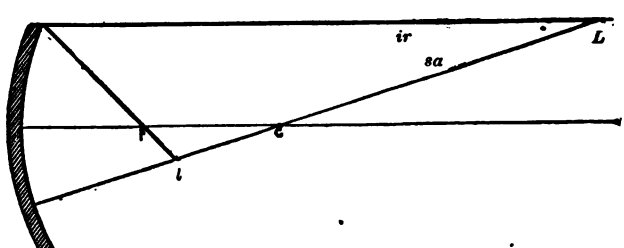


FIG. 130.

on the secondary axis $s\ a$ of L. The ray $s\ a$ is called the secondary axis of L because it passes through L and C to the mirror. The location of the image l may be found either by the same reasoning as in the preceding cases or by selecting a

parallel ray *i r*, which will be reflected through F, *because parallel rays* are *reflected through the principal focus.* Where the reflected ray *r r* intersects the secondary axis *s a* the image *l* will be located.

When the luminous point *L* (Fig. 131), is placed between the mirror and its principal focus, the image *l* will appear to be behind the mirror.

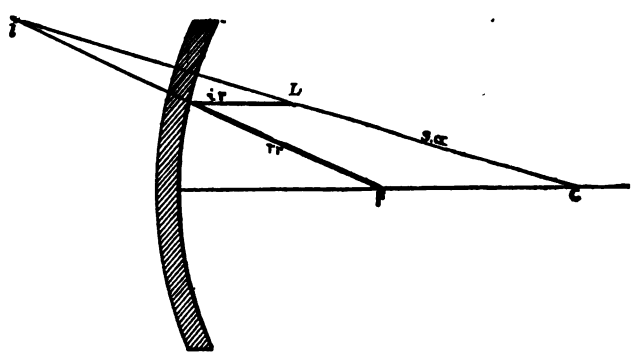


FIG. 131.

Let *L* be the luminous point. Draw the parallel incident ray *i r*, also the secondary axis *s a*. The incident ray *i r* will be reflected through F. Now since the secondary axis *s a* and the reflecting ray *r r* diverge, they will not meet on the concave side of the mirror. Prolong *s a* and *r r* behind the mirror until they meet. At the point *l* the image of *L* will appear to be.

From the preceding cases the following facts are to be observed:—

When the object L is placed beyond C the image l will be between F and C.

When the object is placed between F and C the image will be beyond C.

If the object is placed between F and the mirror the image will be behind the mirror.

Whenever the image and the object are on the same side of the mirror, the image formed is called a *real image*, and it is to be noticed, that it is always formed by the direct union of the reflected rays (Fig. 128 and Fig. 130).

Whenever the object is placed between F and the mirror the image appears to be behind the mirror and is called *virtual image* and is always formed by the prolongation of the reflected rays (Fig. 131).

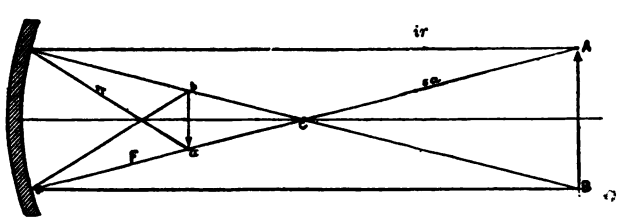


FIG. 132.

Formation of real images. — Let an object $A\ B$ be placed beyond the center of curvature of a concave mirror (Fig. 132).

Draw the parallel ray *r i*. The reflected ray *r r* will pass through the focus. Draw the secondary axis *s a*. Where the reflected ray *r r* meets the secondary axis *s a*, an image *a* of the point *A* will be formed. In a similar manner find the image of *B*. The images of all the points between *A* and *B*, which constitute the arrow, will be formed intermediate the points *a* and *b*. The image will be *inverted* and *smaller* than the object. If the object is placed at *a b* the image will be formed at *A B*. The image will be inverted and enlarged. These images are real images and can be formed on a screen.

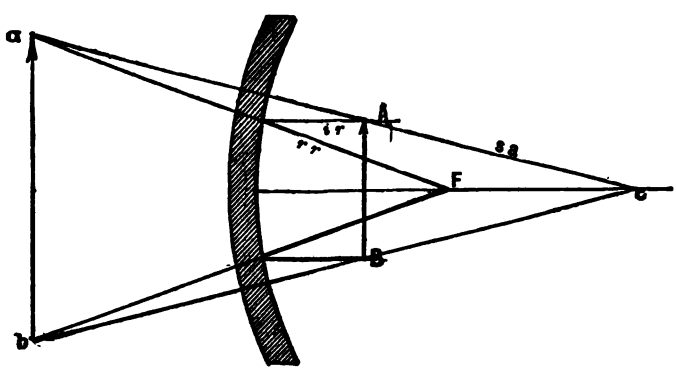


FIG. 133.

Virtual images.— Let an object *A B* (Fig. 133), be placed between a concave mirror and its principal focus. Draw the secondary axis *s a*. Draw the incident parallel ray *i r*. It will be reflected along the line *r r* through the focus. Since the

reflected ray $r\ r$ and the secondary axis will not meet on the concave side of the mirror, they must be prolonged behind the mirror until they do meet as at a. Then a will be the image of the point A. By the same reasoning b will be an image of the point B. The image $a\ b$ will be *virtual, enlarged* and *erect.*

Convex mirrors. — In convex mirrors all the images are virtual and are formed behind the mirror. They are erect and smaller than the object. They may be found in the manner already explained for locating images of concave mirrors.

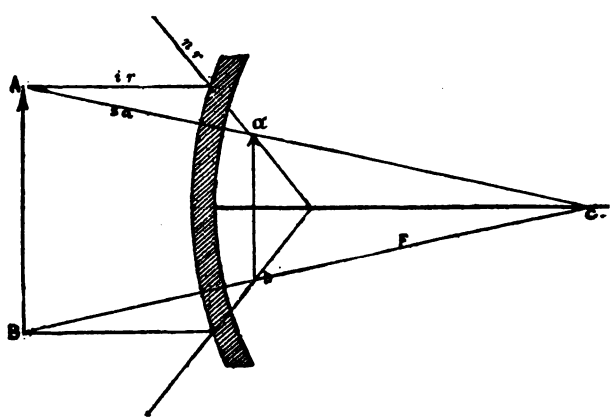


FIG. 134.

Let $A\ B$ be an object placed in front of a concave mirror (Fig. 134). Draw the parallel ray $i\ r$ and the secondary axis $s\ a$. The parallel incident ray from A appears to radiate from a point a on

the secondary axis *s a;* that from *B* as if from the point *b*.

107TH EXPERIMENT.— **Let the direct rays** of the sun fall upon a concave mirror; the rays of light will converge to a point. This is the *principal focus of the mirror.* Measure its distance from the mirror.

108TH EXPERIMENT. — **Place a candle,** in a darkened room, in the principal focus of the mirror. The rays will be reflected parallel, and no image will be formed on a screen.

109TH EXPERIMENT. — **Place the candle** somewhat beyond the center of curvature, which is twice the focal distance, and catch the focused reflected rays on a screen. The image will be *real, smaller, inverted* and between the focus and the center of curvature.

110TH EXPERIMENT. — **Place the candle** between the focus and the center of curvature. The image will be beyond the center of curvature, *real, enlarged* and *inverted.*

111TH EXPERIMENT. — **Place the candle** between the focus and the mirror. The image will be behind the mirror, *enlarged* and *virtual.*

LESSON LXIII.

VISIBLE DIRECTION — REFRACTION.

Familiar Facts. — A person struck by a stone does not seek the person that threw the stone in the direction in which the stone was going after it struck him, but in the direction from which it came. Thus, he whose forehead has been struck by a stone in a downward direction, looks upward for the perpetrator; he supposes him to be in the direction from which the stone came. If struck by a stone in an upward direction, he will look downward to find the evil-doer.

We act in a similar manner when rays of light strike our eye.

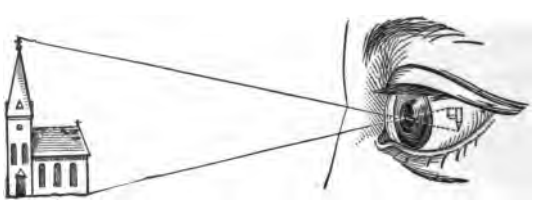


FIG. 135. Image Inverted.

In the case of a boy looking at a steeple, his eye receives its topmost ray in a downward direction. Imagine this ray to be extended after passing through the pupil of his eye and the image on the retina will be found to be inverted (Fig. 135).

Since light travels in straight lines, the ray strikes the *lower part* of his eye in a downward direction. The lowest ray coming from the foot of the steeple would, if extended, traverse the *upper part* of his eye in an upward direction, yet he sees the steeple in its true position.

But if, turning round and then bending his head down to his knees, he looks at the steeple from between his knees (Fig. 136), the topmost ray will, if extended, pass downward through the *upper* part of his eye; and the lowest ray, upward through the *lower* part of his eye. In this case he would see

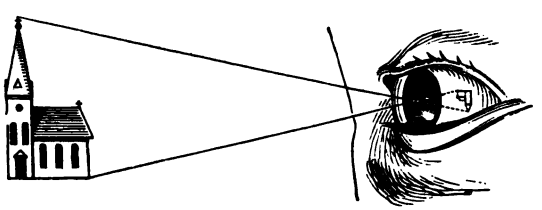


FIG. 136. Image Upright.

the steeple *inverted*, because the image on the retina is inverted, were it not for the fact that *the eye sees an object, or any part of an object, in the direction from which the rays of the object come.* So that he nevertheless sees the steeple in its true position.

All bodies appear to be situated in the direction from which their rays come to the eye.

112TH EXPERIMENT.—**Immerse a pencil** in water perpendicularly; it looks as straight as before. But when immersed obliquely, it appears bent or broken. Oars, when partly immersed, present the same appearance. When the pencil is out of the water, we see it by means of the light diffused from it. Consequently, when the pencil is partly immersed, we see the portion above the liquid for the same reason. The light diffused from the immersed portion, however, must first travel through the water, and then through the air. Now since the immersed portion seems to be bent, it follows that the rays diffused from it are bent; that is, they travel in straight lines through the liquid, but on entering the air, they deviate from their original course. But the eye is in the habit of following the direction of the rays, and must see the pencil. Therefore it seems *bent* simply because the rays coming from it are bent.

Let *ab* (Fig. 137) be the pencil partly immersed; *ac*, the part immersed appears to be at *dc*, because the ray coming from *a*, which ought to pass out in the direction of *a b*, is made to deviate from its course when leaving the water at *c*, and enters the eye in the direction of *de*. The eye, believing point *a* to be in the direction from which its ray comes, sees the point *a* actually as being at *d*. The

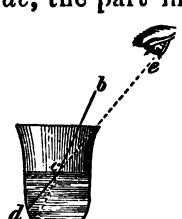


FIG. 137.

same takes place with the other rays entering the eye; hence the whole part *ac* is seen as being at *dc*.

113TH EXPERIMENT. — **A coin** placed on the bottom of a tumbler filled with water is seen in its true direction if viewed perpendicularly; and in a more elevated place, if viewed obliquely. See Fig. 138.

FIG. 138.

Suppose an incident ray of light *i* moving in air (Fig. 139) to meet the surface of water *A B*, then the refracted ray, *r*, would be bent out of its course toward *n*, which is a perpendicular erected at the point of incidence in the water.

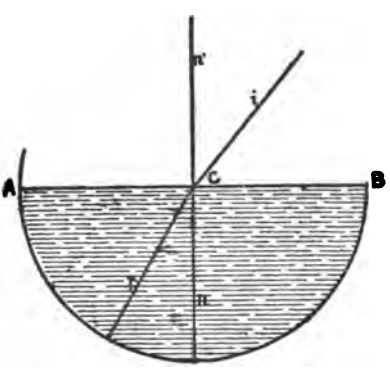


FIG. 139.

Conversely if *r* is the incident ray coming from some luminous point in the water, then *i*, the refracted ray, would be bent away from the perpendicular, *n'*, erected in air at the point of incidence *c*.

The angle *n' c i* is called the *angle of incidence*, and the angle *r c n* the angle of refraction when

the light passes from air into water, as in the first instance mentioned.

Hence *when the light passes obliquely from a rarer to a denser medium, it is refracted toward the perpendicular.*

When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular.

LESSON LXIV.

PRISMS — LENSES.

114TH EXPERIMENT. — **On a blackboard make a** mark in the shape of an arrow, and look at it through a glass prism, which should be held so that only one edge of it is directed upward (Fig. 140). The arrow will

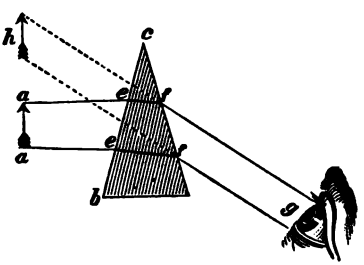


FIG. 140.

then be seen as being above its true place. The reason of it is this: Rays of light, *ae*, *ae*, — we take but two for the sake of simplicity — diffused from the arrow, strike the surface *b c* obliquely, and are, therefore, refracted to *ff*. On passing from the glass prism at *f*, they are again refracted, and enter the eye which is stationed at *g*. But the eye follows the direction of the refracted rays, consequently it sees the arrow as being at *h*.

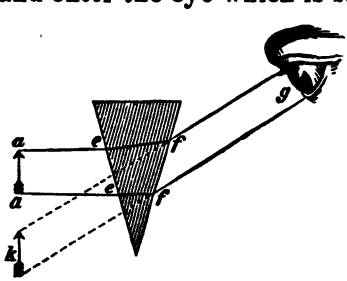


FIG. 141.

115TH EXPERIMENT. — **Now look at the arrow on the black-**

board through the prism inverted (Fig. 141); that is, placed so as to present two edges upward. The arrow will then be seen *below* its true place. The reason of this is the same as before. The rays *ae*, *ae*, are refracted to *ff;* consequently the arrow is seen as being at *k*.

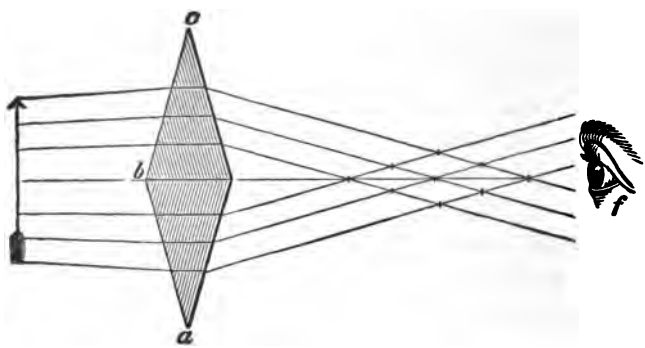


FIG. 142.

If now we place two prisms together, as in Fig. 142, rays diffused from the arrow and entering the glass surface, *a b c*, will, in like manner, be refracted twice, and meet each other in several points behind the prism. In order that the eye of a person situated at *f*, may receive all these refracted rays, and thus be able to see the whole arrow through the prisms, it would be necessary to have these rays blend into a common point. To do this, we must have the surface *a b c* curved (Fig. 143); that is, we must have a curved glass in place of the prisms, in the present case a *convex Lens*, com-

monly called a *Burning-glass.* It not only brings rays of light to a common point, the Focus, but

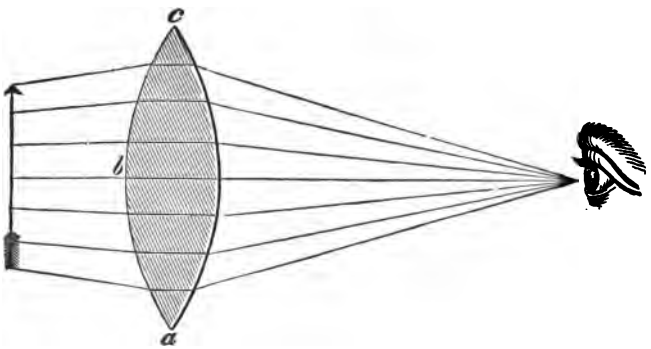


FIG. 143.

also blends rays of heat into a focus. Hence, a match ignites, or a hole is burnt in a piece of paper, if either object be held in the focus of a convex lens, and the lens be turned toward the sun.

Lenses.— A lens is a transparent medium having two curved surfaces, or one curved and one plane surface. Lenses are of two classes, converging and diverging according as they collect rays or cause

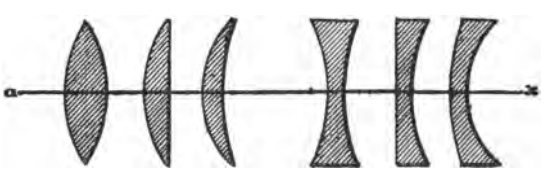


FIG. 144.

them to diverge. Each class comprises three kinds (Fig. 144).

CLASS I.

1. Double-convex
2. Plano-convex
3. Concave-convex

} Converging, or convex lenses thicker in the middle than at the edges.

CLASS II.

4. Double-concave
5. Plano-concave
6. Convexo-concave

} Diverging or concave lenses thinner in the middle than at the edges.

The line *ax*, which passes through a lens perpendicular to both surfaces, is called the *principal axis* of the lens. The *centers of curvature* are the centers of the spherical surfaces of a lens. Any line which passes through the center of the

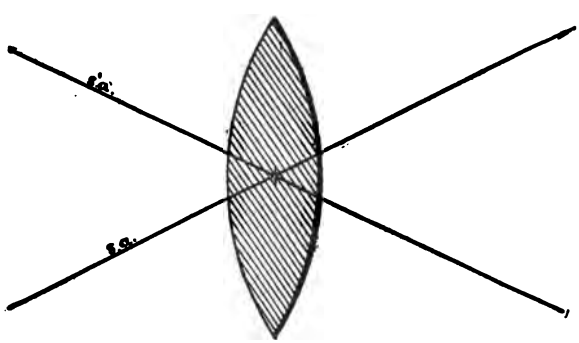


FIG. 145.

lens and does not coincide with the principal axis is called a secondary axis. *s a* and *s' a'* are secondary axes (Fig. 145).

The principal focus of a convex lens is the point where parallel rays unite after refraction (Fig. 146).

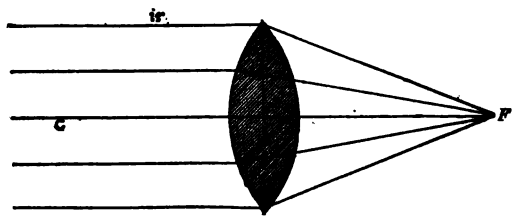


FIG. 146.

Any incident ray $i\ r$ will be twice refracted toward the axis which it intersects as at F. In a double convex lens of crown glass the *center of curvature and the principal focus coincide.* The distance of the point F from the center of the lens, is called *the principal focal distance* and varies with the radii of curvature and also with the kind of glass of which the lens is composed.

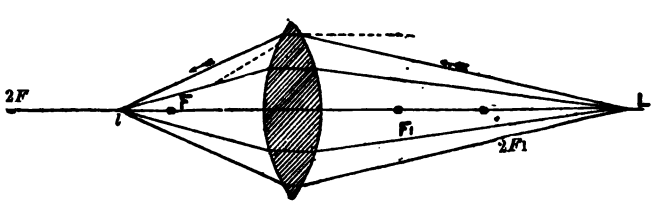


FIG. 147.

Conjugate foci.— When a luminous point L (Fig. 147) sends rays to a convex lens, the refracted rays converge to another point l; rays sent from l to the lens would converge to L. Two points so

associated are called *conjugate foci* and give rise to real images.

If the luminous point be placed at the principal focus (Fig. 146), the refracted rays will be parallel. A lamp so placed will illuminate objects at great distances.

If the luminous point is placed at L beyond $2\,F_1$, which is twice the focal distance, the image l will be between F and $2\,F$, which is more than once and less than twice the focal distance.

If the luminous point is placed between F_1 and $2\,F_1$ the image will be beyond $2\,F$.

If the luminous point is placed at $2\,F_1$, the image will be formed at $2\,F$.

A virtual focus is formed when the luminous point is between the lens and the principal focus (Fig. 148).

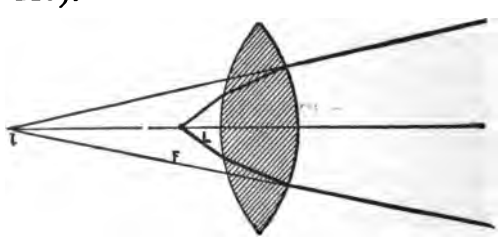


FIG. 148.

Rays of light coming from the point L and striking the lens, will not converge on the other

side of the lens. They will diverge and appear to come from a point *l*. This is a *virtual focus* and is on the same side of lens as the object *L*.

Images formed by lenses.— The construction of images formed by lenses is closely analogous to the process employed with mirrors.

Real images.— Let *A B* be the object placed beyond *2 F* of a double convex lens (Fig. 149).

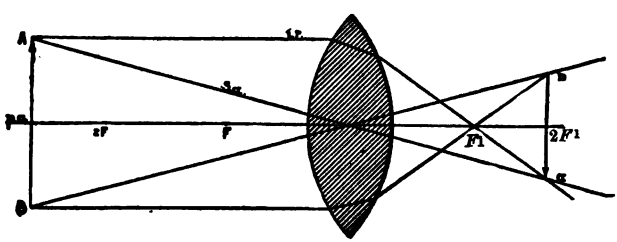


FIG. 149.

Any two of the many rays from *A* will determine where the image *a* is formed. The two most convenient for this purpose are the one that lies along the secondary axis, *s a*, and the one *i r*, which is parallel to the principal axis *p a*. The ray *i r* will be refracted so as to pass through the focus F_1, because it is parallel, and intersect the secondary axis at same point *a*. This is the conjugate focus of *A*. In a similar manner the conjugate focus of *B* may be located at *b*, and all the intermediate points in the arrow. The image is *real*, *inverted*, and *smaller*.

If the object is placed somewhere between F_1 and $2\ F_1$, the image will be *real*, *inverted*, and *enlarged*, and beyond $2\ F$.

Virtual images are formed when the object is placed between the lens and the principal focus.

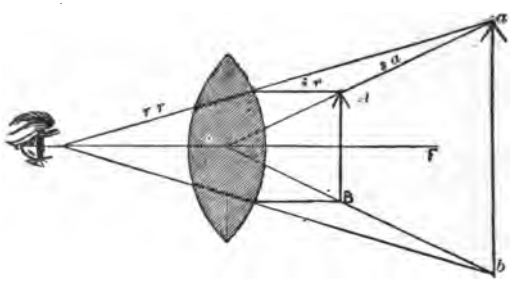


FIG. 150.

In Fig. 150, $s\ a$ is the secondary axis of the point A; $i\ r$ is an incident ray parallel to the principal axis and after two refractures enters the eye and appears to come from the point a. Similarly the point B will appear to be at the point b. The image will be *virtual*, *erect* and *enlarged*. A convex lens used in this manner is called a *simple microscope*.

Concave lenses.— The action of a double concave lens upon light is like that of a convex mirror. It causes parallel incident rays to diverge as if they came from a point, as F. This point is its principal focus. It is a virtual focus (Fig. 151).

Formation of images by concave lenses.— Since the effect of concave lenses is to diverge refracted

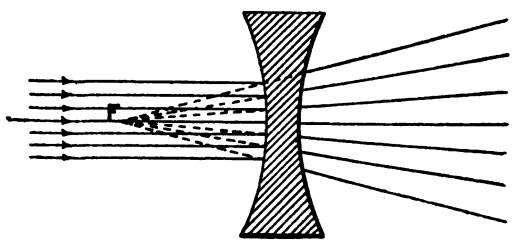


FIG. 151.

rays, the rays coming from A and B (Fig. 152), after refraction diverge as if they came from a and b, and the image will appear to be at a b. Hence images formed by concave lenses are *virtual*, *erect*, and *smaller* than the object.

Spherical Aberration by refraction is due to the fact that the rays refracted near the edge of the

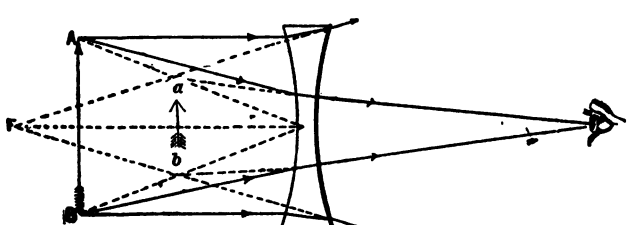


FIG 152.

lens meet the axis a little nearer the lens than the focus of the rays passing through the center. The

effect of spherical aberration is to render the image less distinct and well defined, and is a serious defect in the lenses used in photography. This defect is obviated by means of a circular diaphragm with a hole in the middle which cuts off the marginal rays of light.

LESSON LXV.

COLOR.

116TH EXPERIMENT.—**If a large pasteboard with a small hole be placed facing the sun; or if a room be darkened and only a few rays of light admitted through a crack in the shutter, these rays will pass to the floor, where they form a spot of white light. But if a prism be held before the crack** or before the hole in the pasteboard, the rays of light will be refracted, and spread out in the form of a long band. Instead of being white, this band will be colored. The colors of the rainbow may be distinguished in it, viz.: *Violet, indigo, blue, green, yellow, orange and red.* The colored band is called the Solar Spectrum; and this spreading out of light is called Dispersion. If the spectrum be made to fall upon a mirror, it will be reflected in straight lines like ordinary light (Fig. 153).

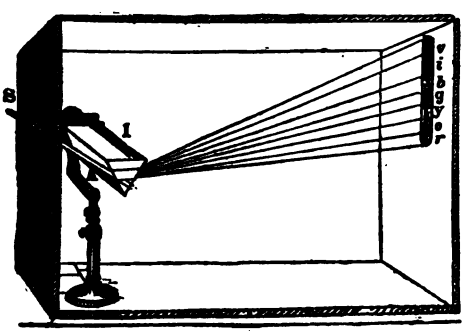


FIG. 153.

117TH EXPERIMENT.— **To convince ourselves** that ordinary sunlight contains the seven colors of the rainbow, let the spectrum produced by one white prism fall upon a second prism of the same size, but placed as shown in the figure annexed. The rays of light, dispersed by the first prism, will be collected by the second and *produce white light again* (Fig. 154).

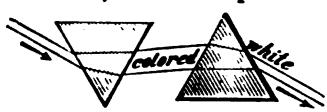


FIG. 154.

118TH EXPERIMENT. —**Allow the spectrum** to fall upon a concave mirror or a double convex lens. A white image of the sun will be formed at the principal focus.

119TH EXPERIMENT.— **The same** may be shown if a top, painted with the seven colors of the rainbow, is set spinning. The impressions made in the eye by these quickly revolving different colors are mixed together, producing a mixture of the colors which is nearly white. The reason why the mixture is not entirely white, is, that we have not all the colors that produce white light

White sunlight is composed of the colors of the rainbow.

120TH EXPERIMENT. — **Between the crack,** or the hole in the pasteboard, and the prism insert a piece of red glass. The spectrum will then be

almost entirely red, and the other colors be found wanting. Insert a piece of green glass in place of the red; the spectrum will be almost exclusively green; with blue glass it will be nearly blue. It is manifest, that white light falls upon each piece of colored glass; and that each time only one color falls upon the prism. Thus when the red glass is inserted, only red light falls upon the prism, and consequently there can be but a spectrum of red light. The question now is, what becomes of the remaining light — or colors — which fall on the red glass? Evidently the red glass *absorbs* all the light except the red, and this it throws out. Something similar takes place with each of the other colored glasses; the green absorbs all the light it receives except the green light; this it throws out. The blue absorbs all the light it receives save the blue, which it throws out and so forth. White glass, however, transmits nearly all the light, and absorbs but very little.

121ST EXPERIMENT.— **If a sheet** of red colored paper be held facing the sun, and a sheet of white paper before it, so as to form an oblique angle with it, the portion of the white paper which is near the red, will appear red. In this case *red rays are diffused from the red paper* and fall upon the white. But the red paper receives white light from the sun, hence it must have *absorbed* all of the white light save the red, which it throws out.

Familiar Facts.— Objects near a blue curtain often have a bluish hue. The curtain receives white light, and absorbs it all except the blue, which it reflects. Objects near the foliage of trees and bushes often have a greenish hue, because green leaves absorb all the light that falls upon them save the green; this they diffuse in all directions, and thus send green light to the objects near by.

122ND EXPERIMENT.— **If, in a darkened room,** a little common salt, placed on the point of a knife, be held in the flame of an alcohol lamp, the flame will be colored yellow. In a darkened room any yellow object held near this yellow flame will look yellow, for it is in the nature of a yellow object to reflect the yellow light that falls upon it. But if a piece of red ribbon, for example, be held near the yellow flame in a darkened room, the ribbon will appear dark grey, or, if the yellow flame is without any white rays, it will appear black. The reason of this is, that a red surface absorbs all the colored rays except the red; hence it absorbs the yellow light it gets from the salt flame, and as it receives no rays which it can reflect, it must appear black.

A body is colored when it reflects only a portion of white light. A body is white when it reflects all the white light; and a body is black when it reflects (almost) no light, that is, when it absorbs all the light.

What causes a black coat to be black? It absorbs nearly all the light, consequently it sends scarcely any to the eye. The eye receives just enough light from it to become aware of its presence, but not sufficient to perceive any color.

Why is every thing black in a dark night? Because, when there is no light, objects receive none, and, therefore, they can send none to the eye.

And objects from which no light is received by the eye, are invisible to us.

Color is not a quality inherent in bodies.

Application.— The application of colors is so manifold, that it is impossible to mention each. They serve to enliven the scenery around us, to improve our own appearance, to indicate joy or mourning. We imitate the thousand delicate hues and tinges of the colors in nature in our paintings, artificial flowers, and in many different contrivances. Colors also serve as signals to be seen from afar, hence their use in light houses, on railroads (colored lights), and with the military (flags), and so forth.

The rainbow is an illustration of a solar spectrum. It is produced by the sunlight passing through drops of water, which act as prisms. It is

composed of the seven prismatic colors. It is the result of *refraction*, *reflection* and *dispersion* of sunlight by falling raindrops. There are sometimes two concentric bows. The inner or primary bow shows the spectrum colors in regular order, the red being outermost; the secondary bow shows the colors in reverse order, the red being innermost.

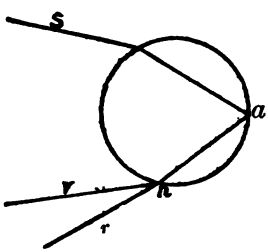


FIG 155.

In Fig. 155 the circle represents a rain drop. A ray of light, S, entering the drop, will be reflected at a to n and at that point escape into the air. In its passage through the drop the ray will be dispersed into its primary colors.

LESSON LXVI.

SPECTRUM ANALYSIS.

When the spectrum of the sun is carefully examined by means of a powerful telescope, it will be found that the colors of the spectrum are not continuous, but that they are interrupted by numerous dark lines, called *Fraunhofer's lines*. There are

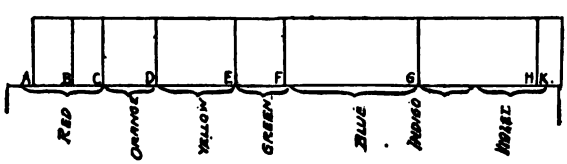


FIG. 156.

about two thousand of these lines. The more prominent are marked *A*, *B*, *C*, *D*, *E*, *F*, *G*, *H*, Fig. 156.

The spectroscope is an instrument used for the production and examination of a spectrum of light from any source. It consists of a tube *A* (Fig. 157) with an adjustable slit through which the light enters and passes through the prism *P* which disperses the light, thus forming a spectrum. The tube *B* is a telescope through which the magnified image of the spectrum is viewed. The third

tube *C* carries a lens, and at one end a fine scale photographed on glass through which passes the light from a candle. The image of this scale passing through the lens is reflected from the face of the prism so that it enters the telescope with the spectrum. Thus the spectrum and the image of the scale will be viewed at the same time. This scale is used to determine the position of certain lines which appear in the spectrum.

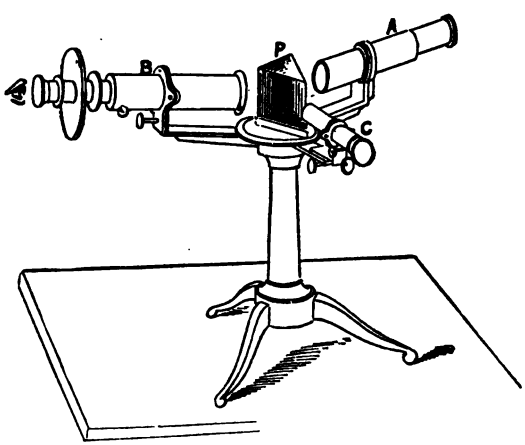


FIG 157.

Three kinds of spectra.— If the light from a white hot solid or liquid be examined with a spectroscope, a continuous band of all colors from red to violet is seen.

This is called a *continuous spectrum* because it is not interrupted by dark lines.

If we examine the light of a glowing *gas* or *vapor*, a spectrum is seen which consists of one or two bright lines. Thus burning salt gives two bright yellow lines, very close together. This is called a *bright line spectrum*. Every substance, when in a condition of glowing vapor, gives a bright line spectrum on a dark background. As these spectra differ in the number and position of their lines, we are enabled to identify substances by means of the spectroscope.

The spectrum given by the sun and the stars is called a *dark line spectrum*.

The spectroscope furnishes us with a method of analysis of far greater power than any previously known. By it, the chemist is enabled to detect the presence or absence of any elementary substance, even when it is combined with other substances. No two substances have a spectrum of the same combination of lines. Hence, when the spectrum of any substance has once been observed and mapped, the presence of that substance when emitting light, can very easily be recognized. It is not necessary that the given substance should exist in large quantities. Thus a portion of common salt less than the $\frac{1}{100000000}$ part of a grain can be detected. By it, the chemistry of the stars has been studied and the extreme generality of the diffusion of the elements in nature has been shown. Many

of the substances known on this earth have been detected in the atmosphere of the stars.

The spectroscope is very useful in the examination of diseased blood, urine, etc., and in the investigation of supposed cases of poisoning.

LESSON LXVII.

POLARIZATION OF LIGHT.

123RD EXPERIMENT.— **Procure Two Pieces** of tourmaline exactly alike from an optician. Hold one of the slices of tourmaline close to the eye and the other next to and parallel with it, so that the light from a window must traverse both in order to strike the eye. (Fig. 158.) Any object beyond the window may still be seen.

FIG. 158.

FIG. 159.

124TH EXPERIMENT.— **Now Place the Tourmalines** at right angles to each other, as shown in Fig. 159. The light from the window will not reach the eye, *and it is said to be polarized.*

If we could see a cross-section of a beam of light, we should see the molecules of ether vibrating in all possible planes as shown in Fig. 160.

For our purpose the vibrations may be considered as taking place in only two sets of planes at right angles to each other as shown in Fig. 161. Now, when a ray of light strikes a slice of *tourmaline,*

only those vibrations which are parallel with the axis or the length of the slice can get through. (Fig. 162.) The other vibrations are quenched by the

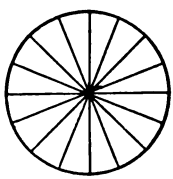


FIG. 160.

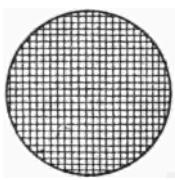


FIG. 161.

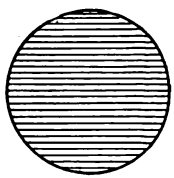


FIG. 162.

tourmaline, and the light is said to be plane *polarized*. Hence, *polarized light consists of a system of vibrations moving in a single plane or in parallel planes.*

Applications.— The polarization of light is used in measuring the strength of sugar solutions, in examining the nature of crystals, in difficult chemical analyses, and in determining whether light from heavenly bodies is reflected from planets and moons or emitted by suns.

LESSON LXVIII.

OPTICAL INSTRUMENTS.

The Camera, used by photographers, consists of a dark box, painted black inside, having a movable screen within it, and a convex lens fitted into an opening in front. Fig. 163 represents one form of the camera.

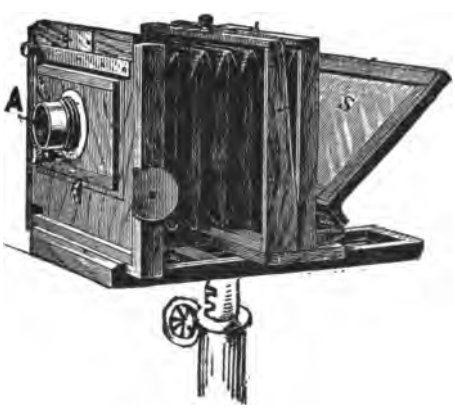


FIG. 163.

A ground glass plate is placed in the frame at *S*, which is adjusted so that a well-defined inverted image of the object in front of the lens, *A*, is thrown upon the plate.

When the focus is well defined, the lens *A* is covered with a cap, the ground glass plate is replaced by a plate covered with a film of nitrate of silver which is very sensitive to the action of light. The cap is now removed from the lens and the image is projected upon the sensitized plate. The chemical changes that light produces in the film are made visible by a process called "developing," and made permanent by a process called "fixing."

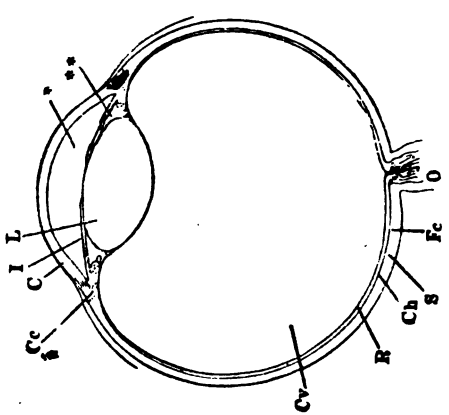


FIG. 164.
The Eye-Ball — Horizontal Section.

S Sclerotic Coat. *C* Cornea.
Ch Choroid Coat. *I* Iris.
Cc Ciliary Processes. *R* Retina
O Optic Nerve (blind spot).
* Aqueous Humor (anter'r chamber).
** Aqueous Humor (posterior chamber).
L Crystalline Lens.
Cv Vitreous Humor.
Fc Yellow Spot (optic axis).

Any number of prints can now be taken from the plate by placing a piece of paper (covered over on one side with a substance sensitive to light) under the plate and allowing the sun's rays to fall upon them.

The Human Eye is a camera. The eye-ball consists of three distinct coats: *the sclerotic, S, the choroid, Ch,* and the *retina R,* and three refracting substances: the *aqueous humor* *, the *crystalline lens, L,* and the *vitreous humor, Cv.* (Fig. 164.)

The refracting substances serve to form a real, and inverted image of external objects on the delicate nervous membrane called the retina, *R.* The nerve fibers of the retina gather into the optic nerve, *O,* the medium of communication with the brain.

The eye, like a camera, must be focused for objects at different distances. This accommodation on the part of the eye is brought about by a change in the form of the crystalline lens. The lens is flattened when a more distant object is viewed (Fig. 165, *A*), and becomes more convex (*B*) when the object to be viewed is nearer.

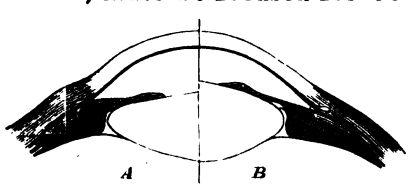


FIG. 165.

Defects of Vision.— Short-sightedness and long-sightedness arise often from a defect in the adjusting powers of the eye. In some persons the ball is too long between the *cornea* and *retina.* Such persons are *short-sighted* (or near-sighted); they can see only near objects distinctly, because objects

at ordinary distances have their rays come to a focus, not on the retina, but in front of the retina. The images of these objects are thereby rendered indistinct, for the rays, instead of blending into points, form minute circles upon the retina, which causes the blurred appearance of the images.

The remedy for near-sightedness is to wear concave glasses, in order to diverge the rays of light and to throw the image further back, away from the crystalline lens.

Long-Sightedness occurs when the distance between the cornea and the retina is so short that the image is formed behind the retina. For this defect, the remedy is to use convex glasses, in order to converge the rays of light which enter the eye and to throw the image further forward, toward the crystalline lens.

The Compound Microscope is an instrument used for the purpose of magnifying images of objects too small to be seen with the naked eye. Fig. 166 represents the simplest possible form of this instrument.

The object, O, is placed just outside of the principal focus of a convex lens or combination of lenses called the *object glass*, L, and a *real magnified*

and *inverted* image, *I*, is formed. This image is formed within the focal distance of another lens, *L'*,

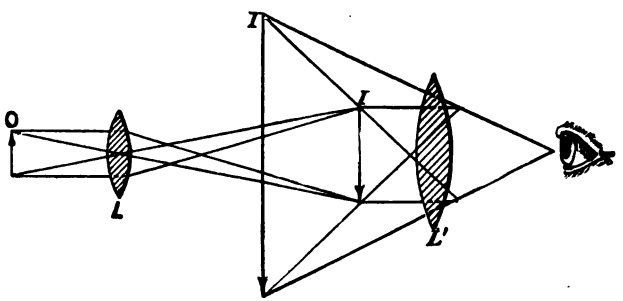


FIG 166.

called the *eye-piece*. This lens forms a *virtual erect* and *magnified* image *I'* of the image *I*.

Fig. 167 represents a simple form of the modern compound microscope.

The body of this instrument consists of a series of brass tubes movable one within the other. In the upper end of the tube is *eye-piece*, *E*. It consists of two lenses. At the other end of the tube is placed the objective, *O*. It usually consists of three very small lenses of very short foci. The object to be examined is placed upon the stage, *S*, which has an opening in the center through which light is reflected upon the object by means of the mirror, *M*.

The magnifying power of a microscope is generally stated in diameters, that is, as 50 or 100 diameters. It is the product of the magnifying power of the eye-piece multiplied by the magnifying power

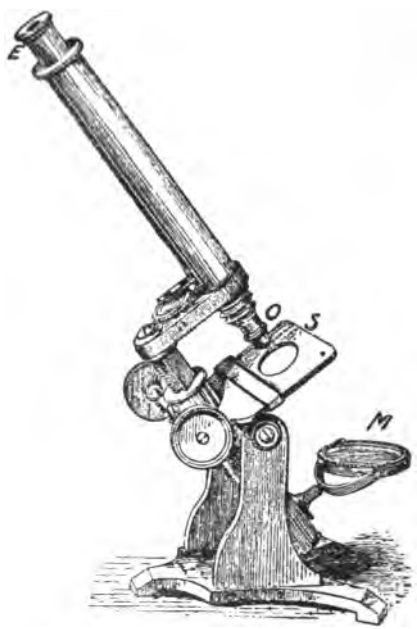


FIG. 167.

of the objective. If the magnifying power of O is 50 and that of E, 10, the image seen will be 500 times the size of the object.

A good combination of lenses in a microscope will magnify 1,000 or even 2,000 diameters.

The Telescope is the same in principle as the microscope. In the latter the object is placed near the focus of the objective, and in the former the object is far away from the objective.

The telescope contains an object glass, *O*, Fig. 168, which forms a *real*, *inverted* and *smaller* image, *a b*, of the object, *A B*. This image is viewed by the eye-piece, *E*, which forms a *virtual* image, *b' a'*, of the real image, *b a*.

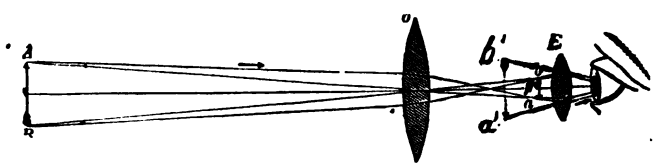


FIG. 168.

The greater the diameter of the objective, the longer its focal length and the tube needed for its use.

The Lick Telescope on Mount Hamilton, California, has a tube 57 feet long. The diameter of the object glass is 36 inches and its magnifying power 180 to 3,000 diameters.

The Spy Glass.—In the telescope the image is inverted. This makes very little difference. The spy glass avoids the inversion of the image by the interposition of two double convex lenses, between the objective and the eye-piece: one to invert the

rays from the image and the other to form a second image for the eye-piece to view.

The Stereopticon. — The stereopticon, magic lantern or projecting lantern, is extensively used in the lecture room for projecting magnified images on a screen.

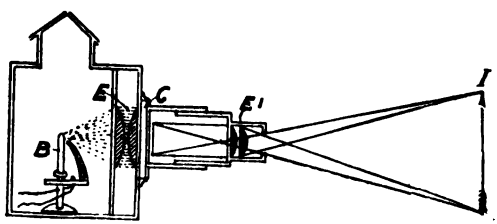


FIG. 169.

An inverted picture photographed on glass is placed in the holder, *C*, Fig. 169. This glass plate is called a slide. It is powerfully illuminated by concentrating upon it, with a large lens, *E*, the rays from some source of light, *B*. The lime light is most commonly used, though the electric light is also used. The lens, *E'*, is called a *condensing lens*, and is used so that a larger amount of light will strike the object placed in the holder, *C*, and pass through the *projecting lens*, *E*, The lens, *E'*, projects a *real*, *inverted* and enlarged image, *I*, of the object upon a screen.

LESSON LXIX.

REVIEW.

188. Bodies emitting their own light are self-luminous.

189. Objects are rendered visible by the impression they make upon the eye.

190. Opaque bodies give rise to perfect shadows. Transparent bodies allow most of the light to pass through them.

191. Light emanates from self-luminous bodies in all directions, and travels in straight lines.

192. All bodies reflect light radiantly.

193. Objects with polished surfaces reflect light, both radiantly and specularly.

194. The angle of *incidence* is equal to the angle of *reflection*.

195. All bodies appear to be situated in the direction from which their rays come to the eye.

196. Mirrors are of two kinds, plane and spherical.

197. Spherical mirrors are of two kinds, concave and convex.

198. Draw an image formed by a plane mirror.

199. Draw a *real* image formed by a concave mirror.

200. Draw a *virtual* image formed by a concave mirror.

201. A real image is one formed by the direct union of the reflected or refracted rays.

202. A virtual image is one formed by the prolongation of the reflected or refracted rays.

203. Draw an image formed by a convex mirror.

204. Two points so associated that one is the image of the other are called conjugate foci.

205. Rays of light, on passing obliquely through substances of different density, such as glass, water, or air, deviate from their course; they are refracted.

206. A lens is a transparent medium having two curved surfaces, or one curved and one plane surface.

207. Lenses are of two classes, converging and diverging.

208. Draw a real image formed by a double convex lens.

209. Draw a virtual image formed by double convex lens.

210. Draw an image formed by a convex lens.

211. The colored band formed when sunlight passes through a prism is called the Solar Spectrum.

212. White sunlight is composed of the colors of the rainbow.

213. A body is *colored* when it diffuses only a portion of the white light it receives; a body is *white* when it diffuses all the white light it receives; a body is *black* when it absorbs all the white light it receives.

214. Color is not a quality inherent in bodies.

215. Fraunhofer's lines are the dark lines which interrupt the solar spectrum.

216. A spectroscope is an instrument used for the production and examination of a spectrum of light.

217. A *continuous spectrum* is one not interrupted by dark lines.

218. The light from a white hot solid gives rise to this kind of spectrum.

219. A *dark-lined spectrum* is one which is interrupted by dark lines. The solar spectrum is a dark-lined spectrum.

220. A *bright-lined spectrum* is produced by the light of a glowing gas or vapor.

APPENDIX.

QUESTIONS.

PROPERTIES OF MATTER.

1. Define matter.
2. Name the essential properties of matter.
3. Name the most noteworthy properties of matter.
4. Define each.
5. Name the three states of matter.
6. Why must meat be cut, while bread may easily be broken?
7. Why is water easily divided, while ice is not?
8. What is the name of the force which causes the parts of a solid to remain together?
9. Why is rolled iron stronger than common iron?
10. Describe an experiment showing that liquids have cohesion.
11. To what purpose does a knowledge of the cohesive force serve?
12. Could birds fly in water?
13. Why would it be difficult for us to walk through molasses?
14. What must be done to break a body?
15. Why has a walking-cane lost its strength if, after being broken, the parts are glued together?
16. Why does oil form larger drops than water?
17. What are pores?
18. Why is a dry sponge smaller than a wet one?
19. What makes blotting-paper remove fresh ink?
20. Why do doors, window-frames and drawers often swell in damp weather?
21. How is it that mercury can be passed through a leather bag?
22. What causes wooden tubs to leak in summer?
23. What may be done to prevent that?
24. How do solids, liquids and gases differ as to their degree of cohesion?
25. Give two applications of cohesion.

ADHESION — CAP. ATTRACTION.

1. How can two leaden bullets be made to adhere to each other?
2. Why do not two bricks adhere in the same manner?
3. When, only, does adhesion take place?
4. How may two rough surfaces be made to adhere?
5. Why does the hand become wet when immersed in water? (Given in text.)
6. Why does it remain dry when drawn out of mercury?
7. Define *adhesion*.
8. Why are two smoothly polished plates separated with great difficulty, if laid together and firmly pressed?
9. Why does fresh paint adhere to one's dress?
10. What is a capillary tube?
11. Define capillary attraction.
12. What causes a sponge to absorb water?
13. Why may eggs and meat be kept fresh in sand?
14. Explain the action of oil in lamp-wicks.
15. How, and why, may grease spots be removed from the floor?
16. Why do two papers pasted together adhere firmly?
17. Why may the hand be drawn out of the water dry, if, before immersed, it was covered with Lycopodium powder?
18. Why is a greased glass not moistened when immersed in water?
19. Why does a small drop of water on a board remain though the board be inverted?
20. Why does a drop of mercury fall when the board is inverted?
21. Why does a small drop of mercury on a tin plate remain when the plate is inverted?
22. Why do figures drawn with the finger upon a window pane, become visible if we breathe on them?

ELASTICITY.

1. Why is the spot which an ivory ball receives upon falling on a blackened surface, larger if the ball has fallen from a considerable height than if it has merely been pressed with the hand upon that surface?
2. What makes an arrow, shot from a cross-bow, fly a great distance?
3. What make steel, ivory and India-rubber resume their former position after being bent?
4. Define *elasticity*. (Elasticity is the property of bodies to recover their former figure, etc.)
5. Mention four applications of the elasticity of bodies.
6. When are bodies hard — soft?
7. Define *brittleness — ductility*.
8. Define *malleability*.
9. Give examples of brittle, malleable and ductile substances.
10. My knife makes a scratch on a substance called *a*, and also on a substance called *b*. The scratch on *a* is the more distinct; which of the substances is the harder?
11. I give you three substances to arrange in the order of their hardness. How will you proceed?

ELASTICITY OF AIR.

1. Show that air, like every other body, maintains its place.
2. Why does not water enter a bottle in the neck of which a funnel is cemented?
3. What causes the air inside a Heron's Fonntain to be compressed?
4. State the principle of Air-chambers in pumps.
5. Describe the action of the pop-gun.
6. Why do fire-wheels turn?
7. Why do sky-rockets ascend?
8. Why do cannons recoil when fired off?

MOTION.

1. Define motion.
2. What is rest?
3. What are the characteristics of motion?
4. What is accelerated motion?
5. What is retarded motion?
6. Give the three laws of motion.

INERTIA.

1. Show that a body at rest remains at rest until set in motion by some force.
2. Show that a body once in motion remains in motion until stopped.
3. State the law of Inertia.
4. Show that for a body to be set in motion, time is necessary.
5. Show that for the motion of a body to stop, time is necessary.
6. Why is a fly-wheel an application of inertia?
7. Mention three examples of bodies keeping in motion after the moving force has ceased to act.
8. What are the chief impediments to motion?
9. Why may the loose handle of a hammer be fastened again by knocking the end of the handle against a hard object?
10. Why may a stopped-up pipe be cleaned again by forcibly knocking against one of its ends?
11. Why must good bridges have a great mass?
12. Why may a candle be shot from a great distance through a board?
13. Why do cannon or rifle balls make a circular hole if fired through a window pane?

GRAVITY.

1. Why does a stone in our hand not fall?
2. Why does it fall when dropped?
3. Why does a pencil fall down from the desk?
4. Whither does a stone thrown into water fall? and why?
5. Whither does a sign-board blown off by the storm fall? and why?
6. Whence do rain, snow and hailstones descend? Why?
7. When does water form water-falls?
8. Why do coals fall through the grate?
9. Why do wall maps and window blinds have rods at the end?
10. What is it that draws clock-weights down?
11. Why does not a suspended object fall?
12. Give the law of gravity.
13. Why have all bodies near the earth a tendency to approach the earth?
14. Why is a string held up at one end, with a weight attached to the other, drawn straight?
15. What prevents the weight from falling?
16. What does the string indicate?
17. Define *vertical*.
18. What is a plumb-line?
19. Give the law of Direction of the Force of Gravity.
20. Why does a large stone press itself partly into the ground?
21. Why do heavy wagons make ruts in the ground?
22. State and explain the third experiment.

FALLING BODIES.

1. In a freely falling body what would be the velocity after 3 seconds?
2. How far will a body fall in 10 seconds?
3. How long will it take a body to fall 100 ft.?
4. A stone is dropped from the top of a cliff and reaches the earth in 4 seconds; how high is the cliff?

THE PENDULUM.

1. Explain the oscillation of a pendulum.
2. What is an oscillation?
3. How many forces act upon it, and what are they?
4. What is a pendulum?
5. Show that the oscillations of the same pendulum, whether quite short or not, take place in the same length of time.
6. Show that a short pendulum oscillates more quickly than a long one.

LEVER.

1. When is a balanced rod in a state of equilibrium?
2. Why will the longer arm of a rod fall?
3. What is to be noticed in lifting the end of the longer arm with the hand?
4. What, if the lengths of the two arms have the ratio of 1 to 2?
5. What characterizes the end of the long arm of a lever?
6. What have hailstones in common with a small weight at the end of a long arm?
7. Define the *lever*.
8. Give a general law about it.
9. What does the amount of power needed to lift a load by means of a lever, depend upon?
10. How may it be found?
11. Give the three important points in a lever.
12. What is a lever of the first class?
13. Give three examples and explain each.
14. What is a lever of the second class?
15. Give three examples and explain each.
16. To which class of levers does the oar belong? and why?
17. The wheel-barrow?
18. How may a heavy stone be lifted?
19. What may the stone then be called?
20. Why are levers used only for moving loads through short distances?

INCLINED PLANE.

1. What is an Inclined Plane?
2. Why does a ball on it fall?
3. Give three familiar instances of an inclined plane.
4. Show that the steeper an inclined plane is, the greater is the velocity of a body falling on it.
5. Show that in that case the force required to ascend it is greater.
6. Show that a body increases in velocity as the space increases through which it falls.
7. Show that the greater the velocity of a body, the greater its striking force.
8. Why does a bullet thrown with the hand inflict less harm than one fired from a gun?
9. Why may hailstones destroy standing grain?
10. State three applications of the inclined plane.
11. Whence the practical application of the inclined plane?
12. What is the principle of the wedge?
13. —— of the ax?
14. —— of the skid?
15. Why are roads leading up steep mountains made in windings?
16. What is meant by the *length* of an inclined plane?
17. What is meant by the *height*?

CLOCKS.

1. What is the main application of the pendulum?
2. Explain its action.
3. What is meant by winding up a clock?
4. What is the office of the crutch?
5. Explain how it comes that *weight* in a clock causes the hands to move with uniform velocity.
6. What is the *motor* force of clocks?
7. What the *regulating* force?
8. Describe the work of an ordinary eight-day clock.

COMMUNICATING VESSELS — HYDRAULIC PRESS.

1. Explain the 24th Experiment.
2. How does water stand in a teapot?
3. Show that your statement must be true.
4. Explain fountains.
5. Define *Communicating Vessels*.
6. Why may water-pipes under ground be said to be communicating tubes?
7. Give law about pressure of liquids.
8. What causes fountain jets to be shorter than they ought to be?
9. How does it come that our water-pipes can lead water to the upper part of houses, contrary to gravity?
10. Explain the action of the hydraulic press.
11. State some of the uses of the hydraulic press.

SPECIFIC GRAVITY.

1. Explain the statement: "Water is heavier than oil."
2. Explain the statement: "Water has greater specific weight than oil."
3. Explain the statement: "Water is denser than oil."
4. Prove that a pound of water has the same weight as a pound of oil.
5. Why has a pint of mercury more weight than a pint of water?
6. Have all solids the same weight?
7. Have all liquids the same weight?
8. Define Specific Gravity.
9. Why does oil float on water?
10. How does it come that smoke rises, while soot falls?
11. Why does oil rise through water?
12. Why do balloons rise through the air?
13. Give law about Fluids of different specific gravities.
14. Why does a piece of wood float, while a stone sinks when thrown into the water?
15. Prove that liquids have weight.
16. Will the weight of a pail of water be increased when a fish is thrown in?
17. Why does an empty flask float on water?
18. Why does it not float in air?
19. Why does a bottle filled with water sink in water?
20. Why does it float on mercury?
21. Under what circumstances does a body float?
22. When does a body sink in water?
23. When will the human body float?
24. Why is it difficult for bathers to walk in water chin deep?
25. In drawing water from a well, why has the bucket more weight as it emerges from the water?
26. Why are heavy stones lifted more easily in water than on dry land?

WEIGHT AND PRESSURE OF AIR.

1. Why does the water not flow from a filled inverted tumbler, with a piece of paper pressing against it?
2. Show that air presses downward.
3. Show that air presses in all directions.
4. Why does not vinegar flow from a barrel whose bunghole is closed?
5. What is a vacuum?
6. What is a rarefied space?
7. Why do we not feel the pressure of air exerted upon us?
8. Why are travelers more easily fatigued on high lands than on low lands?
9. Why is it that, when a bottle filled with air in the low land is taken up on high land, the air will escape with violence when the bottle is opened?

BAROMETER.

1. What may be the height of a col. of water supported by the atmosphere?
2. What is the height of a column of mercury?
3. Comp. the weight, thickness and height of these liquid columns with the corresponding column of air.
4. Suppose we wished to employ water instead of mercury, how high would the barometer tube have to be made?
5. How high with Alcohol — s. gr. 0.9?
6. Describe the barometer.
7. Why does it read the same whether it is in or out of doors?
8. What is the amount of the pressure of air?
9. What are the chief uses of the barometer?
10. Explain its use in measuring heights.
11. —— Its use as an index of the weather.
12. What is the most frequent use of the barometer?
13. What causes the mercury in the barometer to fall?
14. What causes it to rise?
15. To what extent may wind influence the barometer? (Remember that wind is air in motion.)
16. Does atmospheric pressure increase or decrease, as we go away from the earth?

BREATHING — BELLOWS.

1. Why can we, through a tube, suck up water with the mouth?
2. Explain the process of Inspiration.
3. Explain Expiration.
4. What is meant by breathing?
5. What takes place when air has access to a vacuum?
6. Explain the action of the bellows.
7. What is a valve?
8. Compare the action of the bellows with the action of breathing.
9. Explain the act of smoking.
10. That of drinking.
11. Could we breathe in a vacuum? Give reasons for your answer.
12. Would the bellows work in a vacuum? Give reasons.
13. Would the bellows work in water?

COMMON PUMP.

1. Explain the action of the syringe.
2. What causes the water to rise in it?
3. Would it rise if water and syringe, both, were in a vacuum?
4. What are the principal parts of a common pump?
5. Where is the piston when the handle is drawn out farthest?
6. When is the piston at its highest?
7. In that case, what is below the piston?
8. When the piston commences rising, which of the two valves opens?
9. Why?
10. When the piston is at its highest, which valve is closed?
11. What is meant by rarefied air?
12. Why does the water in the suction-pipe rise?
13. What is the position of the valves when the piston is being lowered?
14. What do you pump out first?
15. What causes the water to flow out through the spout?
16. What causes the lower valve to close?
17. What the higher?
18. Give the principle of the common pump.
19. What is a pump?
20. Of what purpose is the lower valve?
21. The upper?
22. Is there any similarity between the common pump and the bellows?
23. Explain your statement.
24. Since the one serves to pump out water, and the other to pump out air, why has the latter but one valve?

FORCE PUMP.

1. How high (theoretically speaking) may water be lifted with a common pump?
2. Give reason.
3. To elevate water to a greater height, what must be used?
4. Give three points in which it differs from the common pump.
5. What are the principal parts of the force pump?
6. Where is the piston when the handle is at its lowest?
   —— When at its highest?
7. When the piston is at its highest what is the position of the valves?
8. When does the lower valve close? and why?
9. When is the upper valve opened?
10. Why does it close? and when?
11. Are both valves ever open at the same time?
    Closed at the same time?
12. Why not?
13. When the piston rises, why does lower valve open?
14. When the piston is at its lowest which valve is open?
15. Why does not the water flow back from the tube?
16. Explain the action of the force pump.
17. Why is it that, by means of this pump, water may be raised higher than by the other?
18. Give the parts of a Hand Fire-Engine.
19. Why does it not have common pumps?
20. Explain its action.
21. What causes the flow?
22. What makes the flow continuous?
23. Give the difference between a Heron's fountain and an air-chamber.
24. Which of the two would work better in a vacuum?
25. How long will either of the two "run?"
26. Comparing the common pump with the barometer, give four points they have in common.
    Seven points of difference.

MAGNETIC ATTRACTION.

1. What is a Magnet?
2. Show that magnets and unmagnetic iron attract each other.
3. Give a property common to both magnetic attraction and gravity attraction.
4. Where does the power of a magnet chiefly reside?
5. What are the ends of a magnet called?
6. What action is seen in two magnets whose like ends are brought together?
7. Give law for it.
8. Describe the Mariner's Compass.
9. How may a piece of soft iron be made a magnet?
10. What is magnetic induction?
11. What effect has a magnet upon hardened steel?
    —— What upon soft iron?
12. What are "Compound Magnets?"
13. What is the "keeper" of a magnet?
14. What reasons might we have for calling the north pole of a magnet its "South Pole," and the south pole its "North Pole?"
15. I place a bar magnet upon a cork floating on water. How will the magnet act?
16. I break a bar magnet into four pieces. How many magnets will there be? How many poles?
17. Describe the use made of the compass of a ship sailing from New York to Liverpool.
18. What leads us to suppose the earth to be a huge magnet?
19. Where is the magnetic north pole of the earth?

ELECTRIC ATTRACTION AND REPULSION.

1. What phenomena take place when electrified sealing-wax is presented to a suspended pith ball?
2. What phenomena occur when electrified sealing-wax is presented to two pith balls?
3. How long do these phenomena remain?
4. What occurs, if first sealing-wax and then glass is presented to the single pith ball?
5. A pith ball passes back and forth a number of times between two substances. Explain the reason.
6. What takes place if to one of the two pith balls you present sealing-wax, and at the same time, glass to the other?
7. How many kinds of electricity? Name them.
8. Give law of electricity.
9. What is lightning?
10. Explain principle and action of Lightning Rods.
11. On rubbing glass on flannel, do you produce only one kind of electricity, or both kinds?
12. Why does an electrified bar of sealing-wax gradually lose its electricity?
13. Why do small pith balls upon a table jump up and down, if a sheet of electrified paper be held over them?
14. What is the cause of lightning?
15. Give three paths which lightning may follow.
16. What objects are most liable to be struck, and why?
17. Why should you not stand under a tall tree during a thunder-storm?
18. Which is the safest place in a room during a thunder storm?
19. On what conditions may a lightning rod be called good?
20. What becomes of the lightning after passing down along the rod?
21. State the purpose of lightning rods.

CHEM. ELECTRICITY — TELEGRAPH.

1. What is an electric element or cell?
2. What is an electric battery?
3. How may a simple electric cell be prepared?
4. How does the current of a cell run?
5. Why must the wire ends as well as all connections about a battery be clean? (Because the current does not leap over.)
6. How may a soft iron rod be rendered magnetic?
7. Prove that the rod just mentioned is magnetic.
8. What is an electro-magnet? and what is the essential part of an electric telegraph?
9. Explain the action of the *keeper*.
10. What is the purpose of the *key*?
11. State the principles of the electric telegraph.
12. How does a submarine cable differ from an ordinary air line wire?
13. How may a street car be moved by electricity?

ELECTRIC BELLS — LIGHT — TELEPHONE.

1. Describe the action of an electric bell.
2. How may electric light be produced?
3. Describe the action of Bell's telephone.
4. Compare Magnets and Electro-Magnets, giving
   (*a*) Four points in common;
   (*b*) Two points of difference.

SOUND.

1. What causes sound?
2. What is sound?
3. What enables us to hear a knife-blade oscillate?
4. Show that sound is the effect of oscillations.
5. How may water or air be set vibrating, or oscillating?
6. Illustrate *noise*, *sound*, and *musical sound*.
7. Could sound be heard in a vacuum? Give reason for your answer.
8. How can you show that solids conduct sound better than air?
9. How does water conduct sound?
10. How do inelastic bodies transmit sound? How does Fog?
11. State and illustrate the velocity of sound in air.
12. Why is the ax of a wood chopper, at a distance, seen to fall before the blow is heard?
13. Why may the distant thunder of cannons be heard better by putting the ear on the ground?
14. Why are the bells of a neighboring place heard ringing at times, and not at other times?
15. Why is it so quiet on the mountains?
16. Why need we not speak so loud on a calm lake as on land?

OSCILLATING STRINGS.

1. Mention the best known musical string-instruments.
2. What is meant by the "fundamental" tone of a string?
3. If a string 20 inches long produces C, what tone will be produced by a string 10 inches long, the strain being the same?
4. If the 20-inch string producing C makes 600 oscillations in a second, how many oscillations will be made by the 10-inch string, other things being equal?
5. If a string be divided into two halves, how will each half oscillate, the strain remaining the same?
6. If a string be divided into four quarters, how will each quarter oscillate, the strain remaining the same?
7. How can you show the truth of the answer to Question 6?
8. Why are the strings of a piano of unequal size?
9. How are the tones produced in a violin?
10. How may sound be "re-enforced?"
11. Describe an experiment showing the re-enforcement of sound.

EVAPORATION, FOG, CLOUDS, RAIN, SNOW, HAIL.

1. Define *evaporate.*
2. When does evaporation take place?
3. What change does it effect?
4. Why is the breath visible in winter?
5. Is all aqueous vapor visible?
6. When is it visible?
7. What name has it then?
8. Under what circumstances does it become visible higher up in the atmosphere?
9. What name has it then?
10. Why do clouds stay in the air?
11. Why do soap-bubbles?
12. Why is it that the higher up the clouds, the greater the rain-drops?
13. What is rain?
14. What is snow?
15. What is strange about hail?
16. Whence the drops on the outside of a tumbler with cold water, in summer?
17. Why do iron safes "sweat?"
18. Whence the moisture on a window-pane when a person breathes against it?
19. When is aqueous vapor condensed?
20. What it meant by *condense?*
21. What is dew?
22. Why is there no dew in cloudy nights?
23. Why none sometimes, although the sky is serene?
24. What is frost?
25. Why do we not have frost in summer?
26. Why does it rain in mountainous countries more than on low land?
27. Has the direction of the watersheds anything to do with the quantity of rain?
28. When does it rain more, in day-time or at night?
29. Give your reasons.
30. Why does it not rain every cold night?
31. Is snow useful? Why?
32. Upon what does the solid state of water, its liquid state and its gaseous state depend?
33. Will it do to compare the atmosphere to a boiler?
34. Give your reasons.

HEAT — CONDUCTION — EXPANSION.

1. Whence the sparks which we see when flint and steel are struck together?
2. —— when a horse is galloping?
3. What effect is produced by rubbing a copper coin on the floor?
4. Why does not a match ignite by being rubbed against glass?
5. Why does it ignite on a brick?
6. Why has he his hands blistered who lets himself down along a rope?
7. Why does a saw feel warm after use?
8. How is heat produced?
9. What may motion be converted into?
10. Why do the hands get warm on holding them to a heated stove?
11. What sensation is felt on keeping the end of a wire in a flame? Why?
12. What is conduction of heat?
13. Why does snow melt more readily on a plank than on a rock?
14. Why are steam-chests and steam-cylinders often covered with wood?
15. Why are the walls of safes often filled with fine ashes?
16. Why do wide garments keep us warmer than tight ones?
17. Why are frame houses warmer than stone ones?
18. Whence the use of good conductors of heat?
19. Why are metallic vessels used for boiling water and other liquids?
20. Whence the use of bad conductors of heat?
21. Give their effect upon warm and cold bodies.
22. Why is less heat given out by a stove when its inner surface is covered with soot?
23. Why is it that the wire (Question 11) may be held longer, if the end in the hand is enveloped in paper?
24. Why have teapots and soldering-irons usually wooden handles? (Text.)
25. When a wire and a piece of paper that have been lying on a heated stove, are touched, the wire feels the warmer. Why?

26. How may expansion by heat be shown?
27. What class of bodies are good conductors of heat?
28. Mention six non-conductors of heat.
29. Why do iron stoves heat well?
30. When is a substance said to cool? Define temperature.
31. Why may ice be kept as well in a feather bed as in an ice chest?
32. Why do mittens keep the hands warmer than gloves with fingers?
33. What advantage in a long stove pipe?
34. Why is a glowing coal rapidly extinguished if placed on iron?
35. Why do double windows keep the room warm?
36. Why does cold wind chill us all through?
37. Why does fruit ripen quicker against a dark wall than when isolated?
38. What advantage in air being a bad conductor?
39. Does fanning us make the air around us cool?
40. Give reason for your statement.
41. Why does drawing the curtains down make a room warmer?
42. Why does snow protect the ground from freezing?

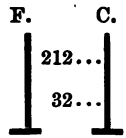
DRAUGHT.

1. Why will paper strips held over a heated stove, move upward?
2. Why will they rise if let go?
3. Why does heated air rise?
4. Explain the revolving of a spiral paper owing to heat.
5. Prove that the air is warmer near the ceiling.
6. When is a flame, held in the upper opening of a room, blown from the room?
7. How about a flame held in the lower opening?
8. Give reasons for your statements.
9. What is draught?
10. What is the cause of draught?
11. Why is a lamp extinguished if the draught is stopped below?
12. Why, if its chimney is closed above?
13. Show that heated air rises, and that colder flows toward the source of heat.
14. How are winds caused?
15. How long does wind last?
16. What is ventilation?
17. Is it sufficient for the ventilation of a room to simply admit fresh air?
18. Prove your statement by a previous experiment.

THERMOMETER.

1. Give the parts of the thermometer.
2. Why the vacuum?
3. Why could not the glass tube be open above?
4. Can you heat the vacuum? and what will be the effect upon the mercury?
5. Why does the mercury expand from heat?
6. Why does the mercury rise? Why does it fall?
7. How are thermometers made?
8. How are the freezing and boiling points obtained?
9. What advantage in dividing the space between those two points into degrees?
10. What advantage in thermometers?

PROBLEMS ON THE THERMOMETER.



To illustrate the problems below, let the two vertical lines annexed represent the two thermometers.

Problem 1.— The mercury stands at 86° F, how will it stand according to degrees C?

Solution: 86° F = 86 — 32 = 54° F above freezing-point. Now, since 180° F above freezing-point = 100° C, we have 9° F = 5° C, or 1° F = $\frac{5}{9}$ C; and 54° = 54 × $\frac{5}{9}$ = 30° C = answer.

Rule I.— To convert any number of degrees F *above freezing-point* into degrees C, first subtract 32 from that number, then multiply the remainder by $\frac{5}{9}$.

Problem 2.— Mercury at 25° C, how must this be read in degrees F?

Solution: 100° C = 180° F above freezing-point, or 5° C = 9° F; hence 1° C = $\frac{9}{5}$ F, and 25° C = 25 × $\frac{9}{5}$ = 45° F above freezing-point. Now, 45° F above freezing-point means 45° above 32° F, so we must add 45 to 32, which is 77° F, answer.

Rule II.— To convert any number of degrees C *above the freezing-point* into degrees F, multiply the number by $\frac{9}{5}$, and then add 32.

Problem 3.— Thermometer at 23° F, how is this read in degrees C?

Solution: Consulting the two thermometers represented above, we find that 23° F means 32 — 23 = 9° F *below* the freezing-point. The problem now is: Resolve 9° F below freezing-point into its equivalent degrees C. Hence we have 9 × $\frac{5}{9}$ = 5° C below freezing-point = — 5° C, answer.

Problem 4.— Thermometer at — 13° F, required its standing in degrees C.

Solution: By inspection we find that the 0 point of the F scale is 32° below the freezing-point, and that — 13° is 13° below the 0 point, that is, 32 + 13 = 45° F, the actual number of degrees F, below the freezing-point. Now, 45° F below freezing-point × $\frac{5}{9}$ = 25° C, below freezing-point, or — 25° C, answer.

Rule III.— To convert any given number of degrees F *below* freezing-point into C, ascertain the difference between 32° F and the number given, and multiply this difference by $\frac{5}{9}$, the product will be — C°.

Problem 5.— Thermometer at — 30° C; give the same in degrees F.

Solution: — 30° C means below the freezing-point; hence — 30° C $\times \frac{9}{5} = 54°$ F below freezing-point. By inspection it will be found that we must subtract 54° from 32°; or, 32 — 54 = — 22° F, answer.

Rule IV.— To convert degrees C *below* the freezing-point into degrees F, multiply the given number of — C° by $\frac{9}{5}$; subtract the product from 32°, and the remainder = answer. If the subtrahend is greater than the minuend, as in the problem above, the difference between the product and 32° is negative, that is, below 0° F, and consequently marked — F°.

THERMOM. COMPARED WITH BAROM.

1. How is the blood-heat point of the thermometer obtained?
2. How is it marked?
3. How did Fahrenheit divide the space between the freezing and boiling points?
4. Where did he *not* commence?
5. Where did he commence?
6. How did Reaumur divide that space?
7. How, Celsius?
8. What are the equivalents of 80° C?
9. What of 50° C?
10. What of 77° F?
11. What of 32° F?
12. What of 17½° C?
13. What of 40° C?
14. What is the healthiest temperature of a room?
15. Where should thermometers be placed?
16. If in New York the mercury stands 85, how would it stand in Paris (according to C°)? (Text.)
17. How in Berlin (C°)? (Text.)
18. According to those scales, what numbers would indicate the blood-heat point? (Text.)
19. Indicate the point of healthiest temperature in Centigrade degrees. (Text.)
20. Give four points which the thermometer and barometer have in common.
21. Four points they differ in.

ATMOSPHERIC ENGINE.

1. Describe Papin's apparatus.
2. Describe the experiment with the same.
3. What causes the piston to rise in Papin's apparatus?
4. What causes it to sink?
5. What is meant by an atmospheric engine?
6. Describe Savery's apparat.
7. Compare it with Papin's.
8. Give Newcomen's improvements on Papin's appar.
9. Explain Newcomen's atmospheric engine.
10. What causes the piston in it to rise? Explain.
11. What causes it to sink?
12. State the principal points of Papin's engine. (Text.)
13. Of Savery's. (Text.)
14. Of Newcomen's. (Text.)
15. Compare Savery's appar. with Newcomen's engine.
16. Compare Papin's with Newcomen's.

STEAM-ENGINE.

1. Who was Watt?
2. Whence his familiarity with the defects of Newcomen's engine?
3. What was its principal defect?
4. What caused this defect?
5. How great a loss was caused thereby?
6. What question arose?
7. What was Watt's first improvement?
8. Explain its result.
9. What did Watt's next improvement consist in?
10. What defect did it overcome?
11. What caused now the piston to rise and sink?
12. Did henceforth the steam merely serve to produce a vacuum?
13. Why was Newcomen's machine a single-acting machine?
14. Why was it used only for pumping water?
15. What constitutes a double-acting steam-engine?
16. What is meant by steam of low pressure? of high pressure?
17. What are high and low pressure engines?
18. What is the use of the sliding valve?
19. Explain action of high-pressure engine.

LIGHT — SOURCES — DIRECTION.

1. How do we obtain perceptions of sound, heat, and of the existence of bodies?
2. What are our sources of light?
3. Mention four self-luminous bodies.
4. What is a self-luminous body?
   (One which makes its own light.)
5. Are the planets self-luminous? Explain.
6. How are images on the eye formed?
7. How are objects rendered visible?
8. Explain the meaning of *opaque* and *transparent.*
9. How are shadows formed?
10. Show that no substance is perfectly opaque.
11. Show that light travels in straight lines.

RADIANT AND SPECULAR REFLECTION.

1. What makes our rooms light in the day-time?
2. How do all objects reflect light?
3. What enables us to see a pencil?
4. A looking-glass?
5. What is radiant reflection of light?
6. Explain the image formed by an object in front of a vertical mirror.
7. Show that there are objects which reflect light also in *certain directions.*
8. What is this kind of reflection called?
9. What class of objects reflect light, both radiantly and specularly?
10. Compare light reflected radiantly with light reflected specularly by

    (*a.*) Giving four points in common.

    (*b.*) Three points of difference.

VISIBLE DIRECTION — REFRACTION.

1. If we receive a sudden blow, in what direction do we look for the cause?
2. Show that a boy looking at a steeple does something similar.
3. On page 296 the two images have opposite directions; why does the person, nevertheless, see the object in only one direction?
4. Give general statement of the case. (All bodies appear to be situated, &c., &c.)
5. Why does the eye see an oar *bent*, the oar being partly immersed.
6. When is a coin on the bottom of a filled tumbler, not seen in its true place and direction?
7. Why do clear waters appear more shallow than they are?
8. What is refraction of light?

PRISMS — LENSES.

1. Show the passage of rays (of an arrow) through a prism with edge upward.
2. Show the same with the edge downward.
3. What is a prism?
4. Show the path of rays of an arrow through two prisms with their bases adjacent.
5. Why the use of a curved glass in place of the prisms?
6. What two names are given to this?
7. What is the Focus?
8. Why the term Burning-glass?
9. How is it that such a lens magnifies objects?
10. Give the general statement true of such a lens.
11. Does a telescope really magnify distant objects?

COLOR.

1. What is dispersion of light?
2. How can it be shown?
3. What effect has it upon white light?
4. Give the principal colors of the rainbow.
5. What is the whole series of colors called?
6. How can you prove that ordinary sunlight contains these colors?
7. Is color a substance?
8. Why does white glass look white?
9. Why does blue glass look blue?
10. Why do objects near a blue curtain have a bluish tinge?
11. When is a body said to be colored?
12. When white?
13. When black?
14. What causes a piece of red cloth to appear red? (Text.)
15. What, a sheet of paper to appear white? (Text.)
16. A black coat to appear black? (Text.)
17. Why is everything black on a dark night? (Text.)
18. Is color a quality inherent in bodies?
19. Is it a property of a body?

GLASS AND CORK WORKING.

The following is taken nearly literally from Vernon Harcourt's excellent work, "Exercises in Practical Chemistry, Clarendon Press, Oxford: " —

1. To Cut a Glass Tube.— Take glass tubing about ⅝-inch external diameter ("hard glass " is preferable). For a Heron's fountain, it should reach from within half an inch of the bottom of the flask to about eight inches above the cork. As mercantile tubing is much longer, a piece of that length should be cut off. To do this, lay the tube on a table, hold it between the thumb and forefinger of the left hand, placed close to where it is to be cut. Take a triangular file, press your left thumb and forefinger firmly against the tube, put the edge of the file upon the tube so as to touch and lean against the thumb, which will thus prevent the file from slipping over the glass, and make a notch on the glass by a few, short, energetic strokes in a forward direction. While in the act of cutting, do not bear down too heavily with the left hand, rather have your left thumb yield a little as the file passes forward, so that the tube may turn a little in the direction of the advancing file. To guard against injury, in case the tube should yield, put on a glove. Now take up the tube, holding it so that the thumb-nails are opposite to each other, with the notch between them, and that you tightly press the tube (where the notch is) with thumb-nail and forefinger of each hand, and with a resolute grasp break the tube (moving your hands in a direction *from* you) as you would break a stick. The edges of the new end will be sharp and rugged; to prevent their tearing the cork, pass the file lightly over them; then hold them a few seconds in the tip of an alcohol (or gas) flame.

For a Heron's fountain like the one in the frontispiece — you should have a bent glass tube.

2. To Bend a Glass Tube.— If the external diameter of the tube does not exceed half an inch, a common gas flame is very suitable; but if the gas is not at hand, a spirit lamp with a large flame may be used. Light the gas, or spirit lamp; then holding the piece of tube by its extremities, bring it a little above the flame, turning it constantly around and moving it laterally so as

to heat about two inches of it equally on both sides. After a few seconds lower it gradually into the flame, still constantly turning it round.

If the gas burner be used, the glass will become covered with soot when immersed in the flame; but this is of no consequence, as the heat of such a burner is never high enough to incorporate the carbon with the glass. When the heated portion becomes soft and yielding, which will take place even before it has acquired a visible heat, withdraw it from the flame, and gently bend it to a right angle, avoiding the use of much force. When the proper bend is completed, lay the tube on a bit of glass in such a position that the heated portion does not come into contact with any cold surface, and leave it to cool slowly.

3. To Make a Glass Jet.—Take the straight tube, previously obtained; heat the tube two inches from one of its ends by holding it to the extent of half an inch in the upper part of a flame. The thumb and forefinger of each hand should hold the glass about an inch from the heated part. The heated part will soon become soft and a little narrower. Then withdraw it from the flame, and draw the heated part out by pulling the two ends of the glass apart. But pull very gently or else the tube will be drawn out too thin; the jet should have about $\frac{1}{8}$-inch external diameter. Gently place the whole on the table before you and allow it to cool; then make a fine notch at the middle of the drawn-out part, and break the tube there. The long part is the jet for a Heron's fountain. If the aperture is too wide, hold it for a second or two in the flame.

4. To Perforate a Cork.—It now remains to fit these tubes — the bent tube and the jet — to the bottle by means of a cork having two holes. Take a good, sound cork, about an inch in diameter, squeeze it until it becomes soft and elastic (a pair of pliers or nut-crackers will serve the purpose of a regular cork-squeezer), then take it up between the second finger and the thumb of the left hand, and place the sharpened end of the smallest cork-borer against it, one end of the cork midway between the center and the edge. Urge the cork-borer into the cork with a twisting motion, as if you were using a corkscrew. Some care will be required to make the hole straight through the cork, so that it may be truly central. Of the proper direction the eye will be the best judge.

And when the cork-borer has penetrated some little way, it will be advisable to turn the cork a quarter round in order that it may be seen whether the axis of the cork-borer and of the cork are still in the same straight line. If not, a slight pressure on the cork-borer in one direction or the other will set it straight. When the borer has penetrated quite through the cork, it may be withdrawn with a twitching motion, and will bring with it a cylindrical plug of cork, leaving a hole, the sides of which should be smoothed with a round file. In the manner make the other hole midway between the center and the circumference. Take a cork-borer rather smaller than the tubing which you have; see that the holes do not run into each other, or pierce the side of the cork. The holes should next be smoothed and slightly enlarged by a rat-tail file, until the end of one of the tubes will just enter them when some little pressure is used. (If much pressure is used, the tube is not unlikely to break, and the splinters of glass may cause injury. The hole should never be so much smaller than the tube as to make it necessary to use much force in passing the latter through it. It is a good plan, also, to wrap the tube in a cloth or handkerchief while it is being inserted in the cork.) Now pass the longer of the two tubes through the cork, with moderate pressure and a twisting motion, until it projects so far as to reach, when the cork is fitted into its place, nearly to the bottom of the bottle. When this is done pass the other tube through the other hole in the cork, until it projects one or two inches on the other side.

INDEX.

(Numbers refer to pages.)

A

Adhesion, 14.
Adhesion, Application of, 14.
Aeriform Bodies, 17.
Air, 127.
  Chamber, 149.
  Pressure of, 136.
  Pump, 138, 139.
  Weight of, 129.
Ampere, 195.
Archimedes Principle, 117.
Attraction, 46.
Attraction, Electric, 177.
Attraction, Magnetic, 162.
Attraction, Capillary, 16.
Atmospheric Engine, 263-7.

B

Balance, 49.
  Hydrostatic, 117.
  Spring, 49.
Barometer, 134.
Barometer, Use of, 137.
Beats, 228.
Bodies, Falling, 51.
  Compressibility of, 6.
  Expansion of, 6.
Boiling, 251.
Brittleness, 20.
Buoyancy, 115, 116.

C

Cables, Submarine, 203.
Camera, 322.
Capillary Attraction, 16.
Capillary Tubes, 15.
Capstan, 96.
Cell, Electric, 192.
Clocks, 97.
Clocks, Pallet of, 98.
Clocks, Escapement of, 98.
Clouds, 255.
Cohesion, 11.
Communicating Vessels, 111.
Compass, Mariner's, 167.
Compressibility, 6.
Coils, Induction, 208.
Color, 311.
Condenser, 270.
Conductors of Electricity, 174.
Crookes Tube, 217.

D

Declination, 169.
Dew, 257.
Dip, 170.
Direction, Line of, 59.
Discharger, 188.
Divisibility, 3.
Ductibility, 20.
Dynamo, 212.

E

Echo, 229.
Efflux, Velocity of, 124.
Elasticity of Solids, 19.
Elasticity of Fluids, 22.
Electricity, 172.
  Positive, 179.
  Negative, 179.
  Chemical, 192.
Electrification, Methods of, 182.
Electric Battery, 193, 194.
Electric Bell, 203.
Electric Light, 205.
Electric Telegraph, 199.
Electric Telegraph Circuit, 202.

Electric Motor, 212, 213.
Electric Units, 195.
Electro-Gilding, 216.
Electro-magnets, 197, 198, 199.
Electro-magnetic Induction, 207.
Electro-plating, 215.
Electrophorus, 185.
Electroscope, 182.
Energy, 77.
  Kinetic, 78.
  Potential, 78.
Engine, Atmospheric, 263.
  Steam, 269, 273.
  Low Pressure, 273.
  High Pressure, 272.
  Fire, 149.
Equilibrium, 61.
  Stable, 62, 63.
  Unstable, 64.
  Neutral, 64.
Escapement of Clocks, 98.
Evaporation, 254.
Expansibility, 6.
Eye, Human, 325.

F

Fire Engine, 149.
First Law of Motion, 31.
Fluids, Aeriform, 126.
Fluids, Elasticity of, 22.
Fluorescence, 218.
Fluoroscope, 217.
Fog, 255.
Forces, 10, 46.
  Measurement of, 70.
  Centripetal, 79.
  Centrifugal, 79.
  Parallelogram of, 57.
Foot Pound, 74.
Fountain, Heron's, 23.
Friction, 10.
Frost, 257.

G

Gases, 126.
  Specific Gravity of, 122.
Gravitation, 46, 47, 48, 49.
Gravity, 10, 46, 47, 48, 49.
  Center of, 58.
  Acceleration of, 51.
  Specific, 120.

H

Harmonics, 233.
Hardness, 19.
Heat, 239.
Heat, Sources of, 239-241.
  Conduction of, 242.
  Covection of, 243.
  Expansion by, 247.
  Unit of, 252.
Heron's Fountain, 23.
Horizontal, 50.
Hydraulic Press, 111.
Hydrodynamics, 123.

I

Impenetrability, 2.
Impediments to Motion, 10.
Images, Formation of, by plane mirror, 284.
Images, Formation of, by curved mirror, 287-294.
Images, Formation of, by lenses, 307-310.
Images, Multiple, 285.
  Real, 307.
  Virtual, 308.
Induction Coils, 208.
Induction, Magnetic, 165.
  Electric, 183.
  Electro-magnetic, 207.
Inclined Plane, 102.
Inertia, 8.
Insulation, 174.

J

Joule's Experiment, 240.

K

Kaleidoscope, 286.
Keeper, 167.

L

Lenses, 302-310.
Convex, 304.
Concave, 304.
Lever, 93.
Lever, Three kinds of, 94.
Lightning, 180.
Lightning Rods, 181.
Leyden Jar, 188.
Light, 281.
Electric, 205.
Nature of, 281.
Reflection of, 282.
Refraction of, 296.
Polarization of, 321.
Arc, 206.
Incandescent, 206.

M

Machines, 90.
Machines, Law of, 106.
Machines, Defined, 90.
Machines, Mechanical Advantage of, 91.
Malleability, 20.
Magnetism, 162.
Magnetism, Laws of, 165.
Magnetism, The Earth's, 169.
Magnetic Field, 163.
Magnetic Induction, 165.
Magnetic Meridian, 169.
Magnetic Needle, 167.
Magnets, Forms of, 166.
Magdeburg Hemispheres, 140.
Mariner's Compass, 167.
Matter, Properties of, 1-24.
Matter, Three States of, 17.
Melting, 251.
Mercury Shower, 142.
Microscope, Compound, 326.
Mirrors, Plane, 284.
Mirrors, Curved, 287.
Molecule, 4.
Momentum, 70.
Motion, 25.
Path of, 26.
Direction of, 27.
Motion — *Continued.*
Uniform, 27.
Accelerated, 28.
Retarded, 28.
Periodic, 29.
Laws of, 30, 31, 35, 36, 39.
Resultant, 33.
Circular, 79.
Perpetual, 106.
Motor, Electric, 212, 213.

N

Needle, Magnetic, 167.
Needle, Declination of, 169.
Needle, Dip of, 169.
Nodes, 232.

O

Ohm, The, 195.
Organ Pipes, 236.
Oscillation, Definition of, 66.
Oscillating Strings, 230.
Rods, 234.
Plates, 234.

P

Parallelogram of Forces, 57.
Parallelogram of Motion, 33.
Perpendicular, 50.
Pendulum, 66.
Pendulum, Mathematical, 69.
Pendulum, Physical, 69.
Phonograph, 237.
Piezometer, 6.
Pinion, 100.
Plumb Line, 48.
Piston Rod, 145.
Pneumatics, 126.
Pneumatic Railway, 132.
Pores, Sensible, 7.
Physical, 7.
Porosity, 7.
Power, 90.
Pressure of liquids, 115, 116.
Prisms, 301.
Projectiles, 54.

Pulley, Fixed, 88.
Movable, 88, 89.
Pump, Air, 138.
Common, 145.
Force, 148.

R

Rain, 256.
Rainbow, 315.
Reflection of Light, 282.
Laws of, 284.
Refraction of Light, 296.
Laws of, 300.
Resultant, 33.
Rest, 25.
Roentgen Ray, 217.

S

Screw, 105.
Segments, 232.
Siphon, 153.
Skid, 102.
Softness, 19.
Snow, 256.
Sound, 222.
Conduction of, 225.
Waves of, 224.
Velocity of, 227.
Interference of, 228.
Reflection of, 228.
Reinforcement of, 234.
Space, 26.
Specific Gravity, 120.
of Solids, 120.
of Liquids, 121.
of Gases, 122.
Spherical Aberration, 309.
Spectra, Kinds of, 318.
Spectrum, Solar, 311.
Spectrum Analysis, 317.
Spectroscope, 318.
Spring Balance, 19.
String Instruments, 233.
Storage Battery, 214.
Spy Glass, 329.
Stereopticon, 330.

T

Tension of Gases, 22.
Telegraph, 199.
Telephone, 210.
Telescope, 329.
Thermometer, 258.
Timbre, 233.
Time, 27.
Toepler-Holtz Machine, 189.
Trolley System, 214.
Tuning Fork, 234.

U

Units, Electric, 195.

V

Vacuum, 132.
Vapor, 126.
Velocity, 29.
Velocity, Virtual, 106.
Vertical, 48.
Vision, Defects of, 325.
Volt, 196.

W

Weight, 48, 70, 89.
Wheel and Axle, 95.
Wind, Instruments, 236.
Work, Definition of, 73.
Symbol of, 74.
Measure of, 74, 75.

X

X-rays, 217.